AN INVESTIGATION OF MOTOR CONTROL FOR SPEECH IN PHONOLOGICALLY DELAYED CHILDREN, NORMALLY DEVELOPING CHILDREN AND ADULTS

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FOR MY DAD, GEORGE ARNOLD HARRIS,
WHO WOULD HAVE BEEN PLEASED

ABSTRACT

Difficulty with phonological acquisition in children is currently widely regarded as a linguistic/cognitive disability but, since speech is a motor as well as a linguistic activity, speech motor control abilities must have a bearing on acquisition of the speech sound system. On the basis of previous studies, measures of speech rate and temporal variability are regarded as indices of level of speech motor control ability.

Evidence was sought concerning the possibility that slow maturation of speech motor control abilities may underlie phonological delay in children. Speech timing characteristics were compared in 12 adult speakers (Group A), 12 normal preschool children (Group N, aged 3;8 years - 4;10 years, mean age 4;3 years) and 12 age-matched phonologically delayed children (Group P). Measurements were made of phrase and segment durations and temporal variability in multiple tokens of an experimental phrase. The phonological structure of the speech data was also analysed and a measure of speech rate (in segments/second) was derived.

The N Group were found to exhibit slower speech rates, generally longer mean phrase and segment durations and higher levels of temporal variability than the A Group. The P Group exhibited significantly slower speech rates than the N Group and there was a trend towards longer phrase and segment durations in the P Group data. With one marginal exception, no significant differences were found between the two child groups on measures of temporal variability. The weight of evidence indicated that speech motor control was less mature in the P Group than in the N Group. The findings lend some support to the view that differences in speech motor maturity may be implicated in phonological acquisition differences. Some implications for the design of therapy procedures are explored. The importance of analysing and taking account of the phonological form of speech data in investigations of speech rate is highlighted.

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INTRODUCTION

Children who, in the absence of known pathology, are delayed in the acquisition of intelligible speech patterns form a large proportion of the case loads of most community based speech and language therapists, (Grunwell,1981; Stark & Tallal,1988). The profession has therefore been concerned throughout its history to understand the nature and causes of this disability.

Since speech production is both a linguistic and a motor activity the normal, gradual acquisition of adult-like speech patterns in childhood must depend upon several factors including neuromotor development, sensory adequacy, perceptual development and cognitive/linguistic aspects of development.

Much research into normal and delayed acquisition of the speech sound system has focused on a 'gross phonological characterisation of children's output' (Edwards J.,1991); that is, adult-like production of speech sounds has been defined perceptually. In these terms there is general agreement that normal children have fully adult-like speech sound systems by 7-8 years of age (Sander,1972). However there is a substantial body of research which has examined acoustic and physiological aspects of speech sound acquisition (for example, DiSimoni, 1974; Eguchi & Hirsch, 1969; Kent & Forner,1979, 1980; Kent,1984; Sharkey & Folkins,1985; Smith,1978; Smith & McLean-Muse,1986, 1987; Tingley & Allen,1975) which has indicated that neuromotor control for speech develops gradually throughout childhood and may not be fully adult-like by as late as 12 years of age.

The investigation reported in this thesis focuses on the relationship between children's phonological (speech sound system) development and the development of speech motor co-ordination and control; that is, the relationship between children's progress towards an adult-like range and organisation of speech sounds and the development of their phonetic (neuromotor) capabilities. The thesis reports an investigation which examines the hypothesis that children delayed in phonological development compared with their peers have less mature speech motor control ability than children of the same age who are acquiring speech without apparent difficulty; that is, that immaturity of speech neuromotor development is implicated in delayed phonological acquisition.

The investigation involved acoustic (spectrographic) analysis and perceptually based analysis of speech data from adult speakers and from two groups of pre-school children. The first phase compared adult subjects with children who were developing speech normally; the second phase compared the results from phonologically delayed children with the results from the adults and normal children.

Acoustic analysis was used to measure temporal features of the data (phrase and segment durations and temporal variability) which, on the basis of previous studies, are regarded as indices of level of maturity of speech motor control. That is, specific experimental hypotheses were formulated on the basis of previous studies involving acoustic measurements of speech data from adults and normal children of various ages, for example DiSimoni, 1974; Eguchi & Hirsch, 1969; Kent & Forner, 1980; Smith, 1978; Smith, Sugarman & Long, 1983; Tingley & Allen, 1975. These studies have revealed a gradual developmental trend throughout childhood towards shorter mean phrase and segment durations and towards greater consistency of temporal and other phonetic features in multiple-token speech samples, and have led to acceptance of acoustic temporal measures of phrase and segment durations and temporal variability as valid indices of level of maturity of speech motor control.

Perceptually based analysis of the phonological form of the data was undertaken with a view to determining what bearing the phonological characteristics of the data from the three subject groups might have on the evaluation and comparison of speech neuromotor ability. This question has not been addressed in previous investigations.

The issue addressed in the thesis has its origin in several domains of study: investigation of development of speech motor abilities in children; investigation of the presenting characteristics and underlying aetiology of phonological disability in children and neurophysiological and neurolinguistic aspects of the motor implementation of speech in mature and developing speakers.

The first chapter of the thesis therefore, reviews relevant aspects of each of these fields of study in order to provide a basis for the reporting of the investigation. The second chapter offers a detailed examination of studies which are immediate precursors of the investigation; that is, studies which have examined the development of speech motor control using acoustic analysis to measure timing characteristics of speech data from adults and children of various ages. Methodological issues arising from this group of studies are discussed. The third and fourth chapters describe the method and report and discuss the results from the two phases of the study. In the final chapter there is further discussion of the results; conclusions are drawn from the investigation in relation to the main hypothesis and the issue of the relationship between development of speech neuromotor abilities and phonological acquisition is discussed in the light of the results; the design of the investigation is critically examined and possible directions for future related research are outlined.

CHAPTER ONE

BACKGROUND AND RATIONALE

This chapter reviews areas of study which provide the background to the investigation reported in the thesis.
The first section focuses on investigation of speech motor control in normal children of various ages in comparison with mature adult speakers and on measures which can provide indices of level of maturity of speech motor control.
The second section discusses the terminology applied to children who, in the absence of known cause, are delayed or disordered in their acquisition of the speech sound system and provides an overview of their presenting characteristics. The third section reviews the literature concerning the aetiology of this disability with emphasis on investigations which have examined general and oral motor factors in relation to phonological disability, and in Section 4 the small group of studies which have attempted to compare speech motor control abilities in normal children and children with delayed/disordered speech and language development are described and discussed.
The fifth section of the chapter gives an overview of the neurophysiological basis for the motor implementation of speech and discusses some of the issues involved in constructing a model of the speech production mechanism.
The final section draws together these various strands, focusing on the importance of the relationship between phonetic (neuromotor) development and phonological development which provides the rationale for the investigation reported in subsequent chapters.

1.1. INVESTIGATION OF SPEECH MOTOR CONTROL DEVELOPMENT IN NORMALLY DEVELOPING CHILDREN.

This section reviews the various kinds of investigation through which the development of speech motor control has been observed and measured, and identifies key indicants of level of maturity of speech motor control ability which have arisen from such investigations.

Studies of speech motor control development taken together indicate that trends which are apparent in the development of other (non-speech) finely co-ordinated motor activities also apply to the development of the motor implementation of speech. That is, as motor control ability develops it is reflected in increased speed of execution; increased consistency of execution; increase in the range and complexity of co-ordinated movements carried out; increased ability to adapt to and compensate for external factors; and increased economy and efficiency of movement.

These various aspects of development in relation to speech motor control have been examined in studies which include acoustic measurements of temporal and other phonetic features in multiple-token speech samples; speech rate and speech diadochokinetic rate measures; direct physiological measurements of articulatory movements; investigations of articulatory compensatory ability; co-articulation studies and investigation of the phonetic development of phonological contrasts.

1.1.1. Acoustic measurement of duration, temporal variability and variability of other phonetic features.

These studies of speech motor control development employ acoustic analysis (usually spectrographic, but in some cases oscillographic) to measure and compare phrase and segment durations and variability of durations and other phonetic features in repeated tokens spoken by children and adults, (Eguchi & Hirsch,1969; DiSimoni,1974; Tingley & Allen,1975; Smith,1978; Hawkins,1973 & 1979 and Kent & Forner,1980).

At the outset of this section it was stated that increased speed and increased consistency of execution are regarded as indices of maturity of performance of any finely co-ordinated motor skill. The results of these acoustic studies taken together indicate with a fair degree of certainty that young children tend to have longer phrase and segment durations (and therefore slower speech rates) than adults and also greater intrasubject context-free variability of duration and other phonetic features, such as vowel formant frequencies, than older children and adults. Kent & Forner's study in particular demonstrates that these aspects of speech production are not fully adult-like even by the age of 12 years, suggesting a gradual developmental progression towards adult-like durational and variability characteristics which extends throughout childhood. The results of this group of investigations therefore suggest that durational measures and measures of temporal variability in multiple-token speech data can provide a valid means of evaluating and comparing speech motor control maturity between groups of subjects. The experimental method in the current investigation which aims to compare speech motor control maturity in phonologically delayed and normal child speakers is therefore based upon such measures. (Further discussion of this group of acoustic temporal studies is deferred until the following chapter where there is a detailed review of results and methodologies.)

1.1.2. Speech rate and speech diadochokinetic rate measurement.

In the motor implementation of speech as in the performance of any co-ordinated movement sequence,

> The time needed for the Central Nervous System to code the motor movements and motor sequences, to transmit impulses to the motor end plates of the muscles generating the spoken signals and, possibly, to scan and modify the ongoing output for accuracy.... (Fletcher 1972, p767)

must impose a constraint on performance. Thus measurement of maximum rate provides a means of quantifying efficiency of speech motor performance at various ages.

In a study involving 384 North American school age children, 24 boys and 24 girls at each age level between 6 and 13 years, Fletcher (1972) measured diadochokinetic (DDK) rates for repetitions of CV monosyllables, disyllables and three-syllable sequences. A highly consistent trend of increase in rate with age was identified. In a similar study with British children between the ages of 4 and 14 years Canning & Rose (1974) also demonstrated that age was a highly significant factor in determining DDK rate. A recent investigation with a younger age range of subjects (3;4 years to 5;8 years) by Henry (1990) showed that both DDK rates for speech sound repetitions and 'non-linguistic rhythmic skills' involving imitation of a variety of stress and rhythm patterns in repetitions of the syllable /ma/ were age related. Henry's study also included a group of 'severely speech disordered children' in the same age-range and this aspect of her study is discussed in section 1.3.2. below.

Articulation rates have also been investigated in connected speech, (for example; Amster,1985 and Walker, Archibald, Cheriak & Fish, 1992). Amster, examining spontaneous speech data, found a systematic increase in articulation rate with age over the age range 2;6 - 5;5 years: Walker et al, in an investigation which examined both spontaneous speech data and imitated connected speech data from 3 year old and 5 year old subjects also demonstrated a developmental trend of increased articulation rate with age, measured in phones per second and in syllables per second.

These studies confirm that measurement of articulation rate can provide a useful indicant of level of maturity of speech motor control abilities.

Some of the studies mentioned above, particularly Walker et al (1992), in addition to investigating age related trends in speech rate, also address the question of interaction of speech rate with a number of other variables such as temporal variability, speaking context and utterance length. Several other studies have been explicitly designed to explore such relationships, (for example, Smith, Sugarman & Long, 1983; Chermak and Schneiderman, 1986). Further discussion of speech rate in relation to these factors is to be found in Chapter Two, Section 2.2.

1.1.3. Physiological measurement.

The most direct approach to the study of speech motor control development is through direct physiological measurement of articulatory movement. For example, Watkin & Fromm (1984) measured mid-sagittal separation of the lips, using a strain gauge device, during vowel productions in three disyllables,

/hæpæp; hɪpɪp; hɑpɑp/. Subjects were required to produce each of the nonsense words five times embedded in a carrier phrase and results showed that variability of lip separation (ratio of standard deviation to the mean) reduced with age until, for 10 year old subjects, variability was similar to that reported for adult speakers by Hughes & Abbs (1976). This result which indicates a decline in variability of articulatory movement with age is consistent with the results of acoustic studies referred to above (section 1.1.1.) and supports the view that variability measurements can provide a valid measure of maturity of speech motor control.

1.1.4. Articulatory compensatory ability

Further evidence of children's immature speech motor abilities in comparsion with adults comes from investigations of articulatory compensatory ability.
Several studies have investigated adult speakers' ability to compensate for impediments to normal articulatory movement; for example bite-block experiments (Lindblom, Lubker & Gay,1979; Fowler & Turvey,1980) and an investigation by Folkins & Abbs (1975) in which jaw elevation associated with bilabial stop closure was unpredictably impeded. Such investigations show that mature adult speakers are able to adapt articulatory movements instantaneously to compensate for such impediments to normal movement. That is, adult speakers display a high degree of 'forced variation flexibility' of articulatory movement (Folkins,1985).

This ability does not appear to be so well developed in young children. A recent study by Edwards J. (1991) which compared vowel productions from six normal pre-school children and adults in normal condition; bite-block condition and clenched teeth condition using acoustic analysis and perceptual judgement showed that the child subjects were less able to compensate fully for the artificially fixed jaw condition than adults. Edwards' results are in accord with two previous investigations by Oller & MacNeilage (1983) and Gibson & McPhearson (1980). However a similar investigation by Baum &Katz (1988), reported in Edwards J. (1991), did not find significant differences in vowel production between control and bite-block conditions for five children with a mean age of 5;2 years. The discrepancy in the findings may be due to different experimental conditions and the particular vowels selected for measurement. (For discussion of these issues see Edwards J., 1991, p15). However the weight of evidence suggests that articulatory compensatory abilities are less well developed in young children than in mature adult speakers.

It is likely that the compensatory abilities of mature speakers depend on the mature operation of neuromuscular servo-systems (sensori-motor feedback circuits) within the articulatory apparatus (see sections 1.5.2.2. & 1.5.2.3. below) and that the poorer compensatory ability of children is related to relative immaturity of these systems; that is, children's poorer compensatory ability is directly related to immaturity of the complex neuromotor systems which underlie speech motor control.

Oller and MacNeilage (1983) suggest that if children do not have extensive compensatory speech abilities this might be a major factor underlying the 'sound errors' which characterise early speech. That is, a child's ability to adapt articulatory gestures in order to achieve a particular speech sound target in the various circumstances in which speech occurs (standing, lying down, during movements of the head and torso etc.) and in a variety of phonetic contexts, may be an important factor in the 'ease of articulation' hierarchy which must in some sense underlie the order in which speech sounds appear in children's output. It certainly seems logical to suppose that young children will favour those speech sounds over which they are able to exercise the most control, that is, those for which they are able to maintain reliable and consistent execution no matter what the physical circumstances or phonetic context. Such an argument highlights the possibility of a strong inter-relationship between development of phonetic (speech motor) ability and development of the speech sound system (phonological acquisition) which is of major concern in this work.

The investigation by Edwards J. (1991) also included two phonologically disordered pre-school child subjects and the results of this aspect of the investigation are discussed below in section 1.4.

1.1.5. Co-articulation studies.

Speech does not consist of a series of isolated gestural configurations corresponding to the phonemes of the language but involves highly integrated sequences of connected, overlapping gestures in which adjacent segments influence one another in complex ways. This co-articulation is generally regarded as reflecting economy and efficiency of movement; and, as such, might be expected to increase with age.

However, results from studies which compare co-articulation in child and adult speech have been ambiguous. On the one hand several investigators have reported results which seem to support a view that co-articulation increases with age. Kent (1983) reports an investigation which revealed less 'target undershoot' for vowel segments (that is, less evidence of co-articulation with adjacent segments) in phrases spoken by children compared with adult speakers. He also cites evidence from an investigation (Kent & Forner,1980) in which multiple repetitions of sentences spoken by adults and children of various ages were acoustically analysed. Results showed that, for example, in the word 'box' spoken by adults the 2nd formant of the vowel rose continuously in anticipation of the tongue-body elevation for the following velar stop; whereas in young children's productions of the word there was a fairly well defined steady state during the vowel segment. On the basis of this and similar evidence Kent suggests that co-articulation is age dependent. However other investigators have failed to find a positive correlation between age and degree of co-articulation, (Sereno & Lieberman, 1987; Smith & McLean-Muse, 1986); and some have suggested that there is **more** co-articulation in younger subjects than in older children and adults (Repp, 1986). Hewlett (1988) found a high degree of anticipatory co-articulation in newly acquired /k/ in a phonologically disordered child which suggests that the length of time a particular segment has been incorporated in a child's output may be significant and may interact with whatever age-related trends there may be. There are currently several different interpretations of the origins of co-articulatory phenomena. For example, the interpretation which arises from an Action Theory / Intrinsic timing theory perspective, (see section 1.5.1.2 & 1.5.1.3. below). This uncertainty together with the conflicting results from studies of co-articulation do not suggest that, with the present state of knowledge, degree of co-articulation can be regarded as a valid index of maturity of speech motor control. (For a fuller review of co-articulation studies in child speech see Hewlett, 1990).

1.1.6. Phonetic development of phonological contrasts.

Studies which examine the phonetic development of phonological contrasts (using acoustic analysis techniques) are also of relevance in tracing the development of speech motor control and indicate that young children are initially limited in their ability to execute and co-ordinate in time the complex combinations of movements required in mature speech production.

The phonological contrast which has been most often examined is the voiced/voiceless distinction in initial plosive consonants. The development of the voicing contrast in English in normally developing children has been studied longitudinally (for example, Kewley-Port & Preston, 1974; Macken & Barton, 1979) and cross-sectionally, (for example, Menyuk & Klatt, 1975; Gilbert, 1977; Barton & Macken, 1980). Three stages of development of the contrast have been identified. In the earliest stage all initial stops tend to be realised with short-lag voice-onset-times (VOT) and are all perceived by a listener as 'voiced'. In the second stage all stop realisations still tend to be perceived by listeners as voiced, but acoustic temporal measurement reveals that voiceless targets are realised with longer lag VOT than voiced targets, although there is still overlap between VOT values for the two target categories. At this stage of development it must be assumed that a child has at least partial 'phonological knowledge' of the voiced/voiceless contrast and is attempting to make the distinction in his output, but as yet lacks the neuromotor control to achieve sufficient contrast, (and sufficient consistency) for the distinction to be apparent to a listener. In the third stage of development VOTs show adult-like division of values in which voiceless targets fall in the long-lag range (40 - 75ms) and voiced targets fall in the short lag range (0 -30 ms). Although, when intra-subject variability of VOT in multiple-token samples is examined it is found that even at this third stage of development children do not match adult levels of consistency (Macken & Barton, 1979).

Hawkins (1984) states that

> The late establishment of mature VOT for long-lag stops has been commonly accepted as resulting from differences in the neuromuscular co-ordination required: short-lag stops are thought to allow considerable variability in the co-ordination of laryngeal and oral activity, whereas long-lag stops demand rather precise co-ordination.
>
> (p 325)

This evidence from developmental studies of the voicing contrast suggests an inter-relationship between gradual development of phonetic capabilities and gradual acquisition of adult-like organisation of phonological contrasts. It is possible therefore that the common occurrence of apparent neutralisation of the voicing contrast in the speech of children with phonological disability can be explained, at least in part, on the basis of immaturity of neuromuscular co-ordination. In other words that an apparently phonological difficulty has its origin in a phonetic (motor) limitation. These studies also suggest that examination of VOT characteristics may provide clues to the status of maturity of children's speech motor control abilities.

Anecdotal evidence to suggest that acquisition of a phonological contrast in normal development depends upon gradual phonetic/motor maturation and learning comes from Hewlett's (1990) account of his daughter's acquisition of the phoneme /r/. There was gradual approximation towards an acceptable adult-like realisation from [j] -> [ɥ] -> [ɣ] -> [ɹ], indicating that awareness of the need to distinguish /j/ from /r/ preceeded the child's phonetic ability to do so in an adult-like way.

Hawkins (1984) reviews studies concerned with the development of the temporal characteristics of speech sounds in relation to the maturation of speech motor control. Hawkins distinguishes between acquisition of control over temporal distinctions which serve as 'primary perceptual cues' and temporal characteristics which do not serve as primary perceptual cues. The former category includes VOT in voiced and voiceless plosives and vowel duration which, in English, serves as a perceptual cue to the voicing of following consonant segments. The latter category includes, for example, reduced consonant duration in clusters. She argues that temporal distinctions which serve as primary perceptual cues are likely to be detected by children early in language acquistion since they signal semantic distinctions, and the distinctions in this category which are within a child's neuromotor capabilities will therefore appear early in the child's output. Naeser (1970), in fact, found that vowel duration ratios are adult-like by approxiamtely 21 months of age. Distinctions which serve as primary perceptual cues but which require neuromotor co-ordination beyond the child's capabilities, such as VOT control, may be realised, but in a non-adult-like way. On the other hand, she argues, temporal distinctions which do not serve as primary perceptual cues would be expected to appear in children's output later than the above category; and in fact it has been shown that, at least in the case of temporal relationships between clustered consonants, the "durational modifications ..... are not developed by 5 years of age and the last ones are probably not mastered until as late as 9 to 11 years of age." (Klatt, 1976 and Gilbert & Purves, 1977, cited in Hawkins, 1984). The evidence from such studies supports the view that speech motor development is a continuous process throughout childhood and that it is intimately linked with the gradual acqisition of adult-like speech patterns both during and beyond the period of overt speech acquisition. That is, phonological development must be regarded as the 'co-emergence of language and a movement system' (Kent 1980).

1.1.7. Summary

These various strands of evidence from several different investigative approaches all support the view that children have poorer speech motor control ability than adults and that speech motor skills go on developing gradually towards adult levels throughout the period of speech acquisition and beyond.

It follows as a logical conclusion from this accumulation of evidence for the gradual development of speech motor abilities that, as for other aspects of motor skill learning, there must be individual differences among children in the rate at which motor control for speech develops. If such an assertion is accepted it follows that since speech acquisition is dependent upon, among other things, adequate neuromotor development, it is possible that one reason for delay in speech sound acquisition might be delayed or deviant development of speech neuromotor skills.

In the following three sections (sections 1. 2., 1.3. & 1.4.) the focus is on those children, who have difficulty, of unknown cause, in acquiring the speech sound system of their langauge.

1.2. PHONOLOGICAL DISABILITY IN CHILDREN

This section discusses the terminology applied to children who, in the absence of known cause, are delayed or disordered in acquisition of speech sounds and describes their presenting characteristics.

1.2.1. Terminology

The terminology used to refer to children who, in the absence of known pathology, have difficulty in acquiring the speech sound system of their native language, has changed in the recent past and has reflected change in perceptions of the nature of the disability.

In the United Kingdom the terms most commonly used before about 1970 were dyslalia (Morley, 1965) and articulatory defect. These terms reflected a view of the disability as centered on the most peripheral level of spoken language encoding - the level of articulator movement. In the United States the term 'functional articulation disorder' was widely used (Powers, 1957; Shelton & McReynolds, 1979). The word 'functional' implies lack of knowledge of the nature of the disability and acknowledges that the disorder does not result from any structural or overt organic defect; nevertheless, traditional approaches to therapy, both in the U.K. and in the U.S., have assumed an articulatory basis for the disability (Grunwell, 1981).

Since the 1970s, as a result of the influence of publications which emphasised the relevance of linguistic theory and description to an understanding of the nature of delayed and disordered child speech, (for example; Beresford & Grady,1967, 1968; Stampe,1969; Ingram,1976; Grunwell,1975,1981), there has been a shift away from an articulation centered view and towards a view of the disability as originating at more central levels of linguistic encoding.

The application of analyses founded on linguistic theory to developing and delayed child speech led to a realisation that children's apparently unintelligible speech was in fact rule-governed and predictable and that their unintelligibility seemed to be caused by a failure to learn, or deduce correctly, the phonological rule system of the language rather than inability to produce the required sounds of the language. Two possible phonological level explanations for the error patterns found in delayed/disordered speech development have been proposed: the error patterns may be due to incorrect underlying representations of the phonological form of lexical items, or may be the result of the application of incorrect 'phonological rules' which relate underlying representations to output forms, (Dinnsen, 1984; Ingram, 1976; Weiner, 1979).

Recent terminology has reflected this change in perception of the underlying nature of the disability and the labels in current use are 'phonological delay/disorder or disability' rather than 'articulatory disorder'. The following quotation represents the generally accepted understanding of these current terms:

> A speech disability at the phonological level involves an abnormal, or inadequate or disorganised system of sound patterns evidenced by deviations in the spoken medium of language. .....the disability is a neurolinguistic dysfunction at the phonological level of cortical representation and organisation of the language system. (Grunwell,1982 p.200)

The contribution which this 'linguistic' perspective and, in particular, various linguistic analysis procedures, for example, Grunwell (1985), 'PACS', have made to clinical assessment and remediation for this client group has been of great benefit. However the consequent, almost exclusive, emphasis on cognitive/linguistic factors in normal and delayed speech acquisition in recent years has led to relative neglect of other more peripheral perceptual and motor factors which must also be relevant in speech development, as the following quotation from Abbs & Kennedy (1982) highlights,

> In a child with so-called phonological deficiencies it can be conceded that articulation errors appear to occur in certain patterns related to features and / or rules hypothesised by one linguistic categorization scheme or another. However, to surmise from this observation that the etiology is linguistic or cognitive may be an oversimplification. It would seem just as plausible, for example, to suggest that this child may not have the normal capacity to develop sensorimotor control and thus cannot learn the intended reactions necessary for executing certain linguistic rule processes consistently.
>
> (Abbs & Kennedy, 1982, p 104)

Indeed, Beresford & Grady (1967,1968) who were among the first in the U.K. to advocate the relevance of linguistic description and theory to the assessment and remediation of deviant child language, used linguistic terms in a purely descriptive way; that is, they referred to 'children with disability at the phonetic and phonological levels of spoken language', but did not use the term 'phonological disorder' as a diagnostic label.

The current use of the term 'phonological disorder' as a pseudo-diagnostic label is unfortunate since it implies a knowledge of the underlying nature and cause of the disability which does not in fact exist. The link between description and the underlying nature of the disability is usually made on the basis of the argument that the children so described have no anatomical defects and can usually imitate most speech sounds in isolation and, therefore, cannot have peripheral production difficulties. That is, the argument is of the 'what else?' kind rather than based on positive empirical evidence.

In this thesis the terms 'phonological disability' and 'phonological delay/disorder' are used in the sense of describing the linguistic level at which the children's difficulties are primarily manifest, rather than in the sense of specifying the underlying nature of the disability.

1.2.2. Speech patterns of children with phonological disability.

Typically the pronunciation patterns of children with phonological disability are characterised by limitations on the number of different segments used; limitations on the range of feature combinations which specify these segments and by phonotactic restrictions which limit the range of syllable structure types in the child's output in comparison with normally-developing children of similar age (Grunwell, 1981)

In the discussion which follows, pronunciation patterns will be described in terms of 'simplifying phonological processes' (Stampe, 1969). This form of analysis provides a useful means of describing children's speech patterns in relation to the adult target system, and has been widely adopted in clinical research and practice. Discussion of the theoretical basis for the notion of simplifying phonological processes; that is, Stampe's 'theory of natural phonology' is to be found in section 1.6. below.

A cross-study survey by Stoel-Gammon & Dunn (1985) uses phonological process analysis to draw together the findings from eight studies which employed a variety of analysis methods. The eight studies, which include both U.K. and U.S. data, involve a total of 128 phonologically disordered, English speaking children between the ages of 3 and 13 years. Nine simplifying phonological processes are identified as having frequent and widespread occurrence across the subjects. These nine processes are: consonant cluster reduction; final consonant deletion; unstressed syllable deletion; stopping; velar fronting; liquid simplification; assimilation and voicing. Of these, cluster reduction, stopping and liquid simplification have the most consistent occurrence across all the studies. (For definitions and examples of these simplifying phonological processes see Ingram, 1976 and Grunwell, 1981 and 1985).

As well as these most commonly occurring simplifying phonological processes, Stoel-Gammon and Dunn also identified several others and found a great deal of intersubject variablility in the type and frequency of occurrence of particular processes.

The findings of this cross-study survey are very similar to the findings in two further studies involving Scottish children of pre-school and first year primary school age, (Moss, 1985 & Howell, 1989).

When the pronunciation patterns of phonologically disordered children are compared with those of younger normally developing children, many similarities are apparent in terms of phonetic inventories, phonotactic constraints and occurrence of simplifying phonological processes (Ingram, 1980; Schwartz, Leonard, Folger & Wilcox, 1980; Hodson & Paden, 1981).

However, the data collated by Stoel-Gammon & Dunn (1985) and also that in Moss (1985) and Howell (1989) include some phonological processes which are **not** commonly found in normally developing speech. Such phonological processes are often referred to as idiosyncratic processes. Examples of processes so labelled are: initial consonant deletion in CV syllables; replacement of consonants by a glottal stop; backing of anterior plosives to velar place of articulation; replacement of stops by fricatives; atypical reduction of consonant clusters and widespread distribution of a 'preferred' sound. However the labelling of a phonological process as idiosyncratic or as 'abnormal' can only be tentative, since the normal developmental data available is as yet limited.

The notion that two categories of simplifying phonological processes can be identified in child speech, that is, 'normal' and 'abnormal' processes, has often been used as the basis for postulating two categories of phonological disability, 'delayed' and 'disordered' or 'deviant',(Leonard, 1973; Ingram, 1976), and this dichotomy is sometimes suggested as a basis for deciding whether a child requires treatment.
Grunwell (1982) draws up a table which gives profiles of typical phonemic inventories and occurrence of simplifying phonological processes at seven successive stages of normal development, from age 0;9 - 1;6 years (Stage I) up to age 4;6 (Stage VII) (see Grunwell 1982, p183). This summary of normal development is often used as the basis for deciding whether a child's speech is deviant or disordered rather than merely delayed. Grunwell suggests that the characteristics of disordered phonological development are:
(i) the persistence of normal processes significantly beyond the usual age of elimination;
(ii) evidence of chronological mismatch in the occurrence of

processes, that is, the co-occurrence of processes which are normally eliminated early, for example velar fronting, along side pronunciation patterns characteristic of much later stages of development, for example the use of consonant clusters;
(iii) the occurrence of unusual or idiosyncratic processes.
Other defining characteristics of disordered phonology have also been suggested, particularly evidence of a static system which fails to progress spontaneously towards more adult-like patterns of pronunciation and evidence of extreme variability of production which does not seem to be associated with change towards more mature patterns, (Stoel-Gammon & Dunn, 1985).

While there does seem to be some basis for considering that some children are delayed in phonological acquisition but following a normal sequence of development, while others display deviant or disordered patterns of development it can be argued that these terms can have only limited validity and clinical usefulness until more data on normal acquisition is available and the criteria for assigning children to either group are more clearly defined. In this investigation no attempt will be made to categorise subjects on the delayed/disordered dimension, particularly in view of the young age-range of the children in the study which makes application of the above criteria even more tentative. The terms 'phonologically delayed' and 'phonological disability' are employed in this thesis to mean that a child's speech patterns are less adult-like than in most children of similar age.

Since the advent of the application of linguistic analysis procedures to the speech of children with phonological disability, there has been great emphasis on the rule-governed and predictable nature of their speech patterns; that is, a rule which applies to a particular class of speech sounds or to a particular combination of sounds is likely to apply to all instances of those sounds in similar contexts. For example; a child who fronts /k/ > [t] in the word 'car' is also likely to do so in the word 'cat'; and a child who reduces the cluster in the word 'spoon' to [p] is also likely to reduce the cluster in the word 'star' to [t], and so on.

Appreciation of the rule governed nature of the speech of children with phonological disability has been regarded as one of the major contributions which linguistic analysis has made in the field of phonological development and disability. However, inconsistency (variability) has also been reported as a characteristic of the speech of children with phonological disability, (Dunn & Davis, 1983; Moss, 1985), and this is born out by clinical experience. The consistency with which a particular indentified simplifying phonological process occurs in a child's speech has obvious importance for assessing the affects of that process on intelligibility and therefore important consequences for clinical decision making. How should inconsistency in a child's pronunciation patterns be interpreted? If a process occurs in all possible contexts on all possible occasions in a child's speech this would imply an absolute limitation on the child's abilities at that point in time, but when a process seems to occur optionally this might be taken to indicate that the child is in the process of 'suppressing' the use of that particular process. That is, sometimes the child is able to achieve an adult-like realisation and sometimes not, or perhaps the child opts for different strategies in different circumstances in the face of a continuing limitation. This question of the interpretation of inconsistent pronunciation patterns is addressed in later chapters in the light of the results of the investigation.

The large body of research on the speech sound characteristics of phonological disorder has tended to focus mainly on the consonant system, and information regarding vowel system characteristics is often no more than anecdotal. Both Ingram (1976) and Grunwell (1982) recognise that the vowel systems of children with phonological disability sometimes show abnormalties, but these are not discussed in a systematic way. A recent paper by Reynolds (1990) reports the most detailed and comprehensive study of vowel system abnormalities to date. Reynold's study is based on data from 20 children who were undergoing therapy for phonological disability. He identifies three groups of vowel system anomalies in these children, which he designates as 'context-free processes'; 'context-sensitive processes', and 'idiosyncratic process'. Context-free processes include 'lowering' of a vowel, which typically affects the group of vowels /ɛ, ɛː, ɛɪ/ resulting in neutralisation such as 'bed'/'bad' -> [bad]; 'fronting' of low back vowels (e.g./ɒ / -> [a]); diphthong reduction, and late acquisition of the stressed central vowel /ɜː/ as in words such as 'girl' and 'purse'. Context-sensitive processes include a lowering or backing effect on vowels which preceed a lateral, as in words such as 'milk', 'hill', 'bell'; and a tendency for vowels to be more open than usual in the context of a following nasal segment. Reynolds also includes specific examples from his data of other 'idiosyncratic' processes affecting vowels and also gives instances of persistent vowel contrast neutralisations in children as old as 10 years whose other phonological difficulties have resolved.

1.2.3. Other linguistic characteristics of phonological disability.

Children who present with spoken language difficulties which are manifest primarily at the level of speech sound system and structure may also display difficulties with other aspects of language. Aspects of their language skills which have been investigated include mean length of utterance, comprehension vocabulary, sentence comprehension, and use of specific syntactic structures. Relevant studies are reviewed by Stoel-Gammon & Dunn (1985); Aram & Kamhi (1982), and Grunwell (1981).

Taken together, results of such studies indicate that disorder/delay in other aspects of language co-exists with speech sound acquisition difficulties in some, but not all, phonologically disordered children: deficits in the expressive use of syntactic forms are the most common associated difficulty, while problems of sentence comprehension have also been found, but more rarely, (Shriberg & Kwiatkowski,1982a & b; Shriberg, Kwiatkowski, Best, Hengst & Terselic-Weber, 1986 and Shriner, Halloway & Daniloff, 1969 (reported in Ingram, 1976).
Howell,Skinner,Gray and Broomfield (1981) found a significant positive correlation between scores on the Edinburgh Articulation Test (Anthony, Bogel, Ingram & McIsaac, 1971) and the Carrow Elicited Language Inventory (C.E.L.I.), an assessment of ability to imitate syntactic structures, (Carrow 1974); and Smith and Bernthal (1983) found that their severely phonologically delayed subjects performed significantly more poorly on the C.E.L.I. than either normally developing or less severely phonologically delayed subjects, while neither of these two studies found any relationship between level of phonological development and performance on sentence comprehension

tasks measured on the Test of Auditory Comprehension of Language (T.A.C.L., Carrow, 1973).

Ingram concludes that such evidence suggests that "deviant phonology may be not just a phonemic disorder, but a more global linguistic one", (Ingram, 1976,p.122).
On the other hand, Menyuk (1971) points out that although it has frequently been observed that children who have syntactic problems, or who are labelled as language delayed, also have phonological problems, it is not so common to find that children who have problems in phonological acquisition also have syntactic problems. That is, phonological disorders often appear to occur in isolation without other obvious linguistic difficulties.
In a large scale survey of 3-year-olds, Randall, Reynell & Curwen (1974) concluded that,

> Difficulty in true (sic) language development does not relate very closely to difficulty in articulation.
> (Randall et al, 1974, p10, quoted by Grunwell,1981,p39)

Severe phonological delay may itself be the cause of delayed development in other aspects of language, and the extreme difficulty of accurately assessing a child's use of syntactic forms while speech remains largely unintelligible because of deviant of delayed pronunciation patterns must be borne in mind, (Conner & Stork,1972).

These findings raise the question of the nature of inter-relationship among various aspects of language performance. That is, where difficulties are found at other linguistic levels as well as at the level of speech sound system and structure the explanation may lie in a common underlying factor (or factors), or in positing a single hierarchical, or non-hierarchical language processing capacity in which limitation at one level, including the level of motor implementation of speech, may have 'knock-on' effects at other levels. Such a 'demands and capacities' explanation is suggested by Panagos, Quine & Klich (1979) who postulate a relationship between syntactic complexity and control over articulation of an utterance, and also by Crystal (1987) who likens the language processing capacity of a developing child to a 'bucket' of certain capacity which may have a "series of holes at a certain level", in which the added pressure of "an extra 'drop' of phonology (syntax, semantics etc.) may cause the overflow of a 'drop' of syntax (semantics, phonology, etc.)" , (Crystal, 1987, p.20).

Although no firm conclusions can be drawn about other linguistic characteristics of phonologically delayed children, there is some evidence that some of these children's difficulties are not confined to one linguistic level. The explanation for these mixed findings is likely to lie partly in the unpredictable nature of individual children's responses to specific or global limitations in language processing capacity and to possible interactions between levels of linguistic processing.

1.3. INVESTIGATION OF FACTORS RELATED TO PHONOLOGICAL DISABILITY IN CHILDREN

This section reviews investigations which have sought to establish predictive or causative factors in relation to phonological disability in children. Since the investigation reported in this thesis is concerned specifically with the relationship between speech motor control factors and phonological disability, emphasis is given here to studies which have examined general, and particularly, oral motor factors (1.3.2.) and other areas of investigation are reviewed more briefly (1.3.3.). Extensive reviews can be found in Winitz (1969); Bernthal & Bankson (1984) and Stoel-Gammon & Dunn (1985). The section begins by considering factors which are prerequisites for normal phonological development.

1.3.1. Prerequisites for normal phonological development and the range of factors which have been examined in relation to phonological disability.

If a child is to acquire adult-like speech patterns in the expected time span, all the peripheral and central processes which underlie language acquistion in general and phonological acquistion in particular must be intact and functioning adequately at the required time. Adequacy of linguistic input must also be an important factor. Since the act of speaking is a social, linguistic, cognitive, and motor activity, prerequisites for normal speech acquisition must

include all of the following:
(i) an environment which provides opportunities and motivation for social interaction and which provides sufficient quality and quantity of linguistic input in a context which is conducive to learning;
(ii) auditory sensory and perceptual abilities adequate to the task of discriminating among the speech sounds of the language; visual abilities are probably also of significance (Mills, 1983));
(iii) memory and cognitive abilities sufficient to allow for the integration and categorization of incoming information from various sensory modalities and adequate to the problem-solving task of formulating, testing and revising hypotheses about the nature of the target system;
(iv) adequate neuromotor control over the muscle systems involved in speech production (respiratory, phonatory and articulatory systems), including adequately functioning kinaesthetic and proprioceptive feedback channels.

It is therefore possible that temporary or permanent inadequacy in any of these spheres during the period of speech acquisition could result in a child failing to acquire intelligible speech patterns at the usual time, and it follows that children who present with difficulties in the acquisition of adult-like speech patterns may not be a homogeneous group in terms of underlying causation, but that inadequacy or slow maturation in any of these areas may underlie a child's presenting problems.

A large body of studies, from the 1940s to the present day, has been concerned with identifying factors related to articulatory/ phonological disability in children. Since the earlier of these studies were carried out before the period in which linguistic terminology and analysis was applied to children's delayed and disordered speech it is, in some cases, difficult to assess the extent to which results might apply to the group of children now labelled as phonologically delayed or disordered.

Studies fall into three main categories:
(i) correlational studies which explore whether articulatory (phonological) abilities covary or coexist with other variables, for example, Arndt, Shelton Johnson & Furr (1977);
Shriberg, Kwiatkowsky (1982a & b) and Shriberg, Kwiatkowsky et al (1986);

(ii) studies which examine the statistical significance of differences between normally developing and phonologically delayed children on measures of particular variables which may have a bearing on speech sound acquisition;
(iii) studies which have reported correlations between improvement in phonological performance and improvement in other aspects of behaviour which have been the focus of intervention, for example Williams & McReynolds (1975); Hill, Howell, Waters & Dean (1989); Howell, Dean, Hill & Waters (in press).

1.3.2. Investigation of motor factors in relation to phonological / articulatory disability.

Because speech is a motor as well as a linguistic activity, the relationship between articulation skills and motor co-ordination in general motor tasks, facial motor tasks and oral motor tasks has been the focus of much investigation.
Powers (1971) states that

> Since speech is admittedly a complex process of delicate muscular adjustments, it has been natural to suppose that cases in which articulation was defective might have less than average precision, speed, strength and control of movement.
> (Powers,1971, p.733)

Most of the research on general motor co-ordination in relation to articulation performance in children and in adults was carried out prior to 1965; for example, Wellman et al (1931), Carrell (1937), Bilto (1941), Mase (1946), Prins (1962) and Jenkins & Lohr (1964). Results tended to be inconsistent and inconclusive and offered little to suggest that individuals with articulation problems have significant difficulties in general motor co-ordination. In the following review only those studies of general motor co-ordination which also include examination of oral motor co-ordination and/or examination of rhythmic abilities, such as tasks involving imitation of tapped patterns, will be discussed.

An area of investigation closely related to the examination of general motor co-ordination was that concerned with laterality in normal and speech/language disordered groups, and in this area too results were inconclusive.

Johnson & House (1937) studied eye and hand dominance in 33 normal and 33 'articulatory defective' children between the ages of 6 -12 years. No differences between the groups on eye dominance were found, but a significantly greater number of disordered children were found to be ambidextrous and left handed than in the control group. However, this result was not supported by Everhart (1953) who reported no differences between control and experimental groups on measures of handedness. Morley (1965) found no differences in laterality between normal children and a group labelled as 'dyslalic', but a group described as having articulatory apraxia , that is, more severe speech sound difficulties than the dyslalic group, showed significantly higher incidence of cross laterality and ambidexterity.

Perhaps the most interesting of the motor co-ordination studies from the 1940 -1960 period was that by Albright (1948) because it included a high proportion of oral motor and speech tasks. His subjects were college students selected to represent the extremes of articulatory proficiency, assessed by six independent judges who were members of the faculty of speech and drama department of Stanford University. There is nothing in Albright's description of his subjects to suggest that the speech of the 'poor articulators' included articulatory imprecision which resulted in neutralisation of phonological contrasts, but it may be reasonable to assume that these adults had experienced difficulties with phonological acquisition in childhood. Subjects were tested on a large battery of tasks involving control, speed and co-ordination of gross body movement, and movements involving the speech mechanism: non-speech mechanism tasks included tests of repetitive tapping, hand steadiness, writing rate, rail walking, tapping in time to an auditory pattern and a task involving timed rotation of a hand drill which required smoothly co-ordinated repetitions of a fixed hand/arm movement (the 'Miles speed rotor task'): speech mechanism tasks included measurement of speech rate in timed recitations of the rhyme 'Mary had a little lamb', with instructions to say it as rapidly as possible; repetitive tongue movements (repeating the syllable [lɑ] at maximum speed), teeth clicking rate, lip movement speed (rapid repetition of the syllable [mu]), and speech diadochokinetic rate measured in timed repetitions of the utterance [tʌkə].
Significant differences were found between the subject groups on two

of the non-speech tasks; the 'Miles speed rotor' and tapping to an auditory rhythm, the latter showing the most highly significant difference. Albright stresses that these tasks, unlike the other non-speech mechanism tasks, involved factors of rhythmic ability and the latter task also involved auditory - motor co-ordination which may mean that it is more closely related to abilities required in speech. All the speech mechanism tasks, with the exception of the teeth-clicking test (which did not involve the production of speech sounds), showed significant differences between the subject groups. With regard to the significantly slower speech rates found in the 'poor articulator' group of subjects, Albright remarks that,

> Considering the fact that 'good speakers' were not selected on the basis of any test of speed .... this superiority in speech rate suggests the importance of the speed of speech movements as a factor in articulation.
> (p.171)

Albright also examined correlations between scores on the various tasks and found that among the tasks where significant difference between groups had been identified, the 'good speakers' tended to show higher correlations between task scores than the 'poor speakers'. He suggests that there is, therefore, a

> Possibility that subjects with good articulation tend to be more stable in their neuromuscular performance and that their fine co-ordinations function with more stability as well as speed.
> (p.172)

Albright's results seem to indicate that adult speakers judged to be 'clear' or 'good' articulators are superior to 'poor' articulators in fine rhythmical co-ordination of movements, especially those which involve auditory-motor co-ordination and/or speed of movement of the articulatory system.

Maxwell (1953) also studied the relationship between general and specific motor skills and articulation in matched groups of male children with normal and 'defective' articulation, (13 boys in each group at ages 7, 8 and 9 years). Tasks included DDK rates for tongue, lips and jaw movements using repetitions of single syllables [tɑ], [kɑ], [pɑ] and [lɑ], and repetitions of the combination [pɑtɑkɑ]; DDK rates for hand movements in tapping and ball-bouncing tasks; eye - hand co-ordination in dot-tracing, Seguin form board, and putting pellets into a bottle; hand steadiness using a cube stacking task, and a group of balance and gait measures. Maxwell found some significant differences between control and disordered groups on DDK rate using [pataka] (all ages); DDK rates using [la] (8 and 9 years only); speed and accuracy of dot-tracing and of placing pellets in a bottle (non-preferred hand); hand steadiness and the tapping and ball-bouncing tasks (7 years only), but he concluded that there was no general agreement from his results which would reliably measure or predict differences between normal children and children with 'defective' articulation at various ages.

Carrell (1937) compared normal and 'speech defective' children on tasks of tapping, tracing, and a 'kinaesthetic imagery task' involving the arms, and found that on all these tasks the control group performed better, although the statistical reliabilities were low. The biggest differences were found between the controls and the most 'severely defective' subjects.

Other investigations from the same period gave conflicting results. For example, a study by Karlin, Youtz & Kennedy (1940), apparently concluded that motor speed, among other factors may "operate to produce dyslalia "; (this is reported in Powers (1971), but no further details of the study have been traced): while on the other hand Mase (1946) who tested normal and 'articulatorily defective' boys in U.S. school grades 5 and 6 on tasks including rapid side-to-side tongue movements, rapid alternating jaw and lip closure, tongue tip movements and rapid repetitions of the word 'Daddy', found no significant differences between experimental and control groups.

The results of these studies on motor co-ordination, viewed as a whole, are far from conclusive but they leave open the possibility that differences in performance on co-ordinated, rhythmic motor tasks, particularly oral motor tasks, may exist between normal individuals and those with speech sound difficulties. That is, there are indications among results of these studies which suggest that the possibility of a link between articulatory / phonological ability and rhythmical fine motor co-ordination of movement in general, and of the speech musculature in particular, should continue to be considered.

In fact, as a consequence of the inconclusive findings from studies of motor co-ordination up to the mid 1960s this line of enquiry was pursued less vigorously in following years; however, interest in a variety of aspects of oral motor and general rhythmic abilities in relation to speech performance has continued intermittently.
A more recent study (Amorosa, 1982) examined timing ability in speech and in hand co-ordination tasks in normal and language delayed children, described as 'dysphasic', aged between 5 and 12 years. This study examined variability of segmental and suprasegmental timimg parameters in repetitions of nonsense syllables and in longer utterances, (which will be discussed in section 1.4. below), as well as variability in timing a finger tapping task. Results showed significantly higher levels of variability in both the speech and hand co-ordination tasks among the language impaired subjects. Amorosa concludes that a "general impairment of timing may be the basis for the (language) deficit in these children."

Shields (1981), following a rather different but related line of enquiry, studied the rhythmic abilities of 75 normal and 35 language disordered subjects aged between 3 and 7 years. The criterion for inclusion in the disordered group were based on performance on the Reynell Developmental Language Scales (RDLS) (Reynell, 1985) and did not specifically include assessment of speech sound development. Shield's study showed a developmental progression in the rhythmic abilities of the normal children throughout the age range 3-7 years and showed that in the language disordered group rhythmic abilities lagged behind chronological age by a similar amount to scores on the RDLS.

Interest in speech diadochokinetic (DDK) rate in normal and speech disordered children has continued up to the present time; for example, a study by McNutt (1977) examined repetition rates for nonsense syllables in normal and articulatorily delayed children and found significantly slower rates of performance in the delayed group. The investigation involved 15 normal children; 15 children who 'misarticulated /s/' and 15 children who 'misarticulated /r/'. The average age of the subjects was 13 years with a range from 12 to 15 years. Both experimental groups had significantly slower DDK rates, measured over repetitions of /dʌgə/ than the normal group.

An important recent contribution to this area of investigation has been made by a study by Henry (1990) in which DDK rates, auditory sequential memory and 'non-linguistic' rhythm were measured in pre-school children aged between 3 and 5 years. (The normative DDK data from this study were referred to in section 1.1.2. above, and auditory sequential memory results are described in section 1.3.3. below). Subjects were 60 normally developing children and 30 children with 'severe speech disorders' chosen from patients attending the Nuffield Hearing and Speech Centre. DDK rate was assessed by three sub-tests involving repetition of a single syllable [tə]; a two-syllable sequence [dʌ bə] and a three-syllable sequence [kʌ pʌ tə]. Henry's test of non-linguistic rhythm was based on the Test of Rhythm and Intonation Patterns (TRIP, Koike & Asp, 1979) and required subjects to repeat various rhythm and stress combinations of the syllable [mɑ]. The results indicated that the speech disordered group had severe problems on all three tests compared with their non-speech disordered peers.

Henry explains that she chose not to select her subjects on the basis of diagnostic category and to use the term 'speech disordered' to "avoid a terminological debate" (p.123). However she describes her disordered subjects as within normal limits of hearing, intelligence and verbal comprehension and as having "severe articulation problems, multiple articulation errors .... and unintelligible connected speech to anyone outside their family circle." In addition to their speech sound acquisition problems the children all presented with "some degree of expressive language difficulty, although none were non-verbal". None of the group had any physical, structural abnormalities but "some showed some difficulty in neuromotor control of the speech apparatus and additional fine motor co-ordination difficulties".
This description would seem to place these children at the extreme of articulatory /phonological disability and indeed these may be children who would tend to labelled as dyspraxic rather than phonologically delayed or disordered. It may be, therefore , that these results have little relevance to less severely disordered children such as those in the present investigation: on the other hand, Henry's highly statistically significant results may indicate that children at the extreme of articulatory / phonological disability are those for whom clear differences compared with normal

performance on oral DDK rate and oral rhythmic tasks can be demonstrated, whereas such differences are much less easily identified in children with less severe speech difficulty.

In summary, the often inconclusive and sometimes conflicting results from studies of general and oral motor co-ordination, combined with the effects of an increasing emphasis on linguistic and cognitive aspects of speech acquisition and disability in recent years has led to a relative neglect of consideration of motor factors in speech development and disorder (see section 1.2.1. above). However, the growth in availability of objective instrumental acoustic analysis techniques has, in the last twenty years or so, led to a wide-spread renewal of interest in investigating motor-control aspects of speech development and disability. Investigations which have utilized acoustic measurement techniques such as oscillographic and spectrographic analysis to study speech motor control in normal children of various ages and in adult speakers were dealt with briefly in section 1.1.1. above and will be reviewed in more detail in Chapter Two. The smaller number of studies which have used similar techniques to compare speech motor control in normal children and children with speech and language disabilities are described in section 1.4. below.

1.3.3. Investigation of other factors in relation to phonological disability.

In addition to the motor factors considered above, investigators have examined oral/facial structural factors; oral sensory abilities; social, environmental and personality factors; auditory perceptual and processing abilties and cognitive and linguistic factors in the search for variables which might be predictive of phonological / articulatory disability.

Of these areas, those most closely related to the motor aspects discussed in the previous section are the investigation of oral/facial structural factors and oral sensory abilities.

Relationship between articulatory performance and sub-pathological variation in the structures involved in articulation was examined in several studies. Oral and facial characteristics which were

investigated include lip dimensions (Fairbanks & Green,1950); dental occlusion (Bernstein, 1954); tongue dimensions and length of lingual frenulum (Fairbanks & Bebout, 1950; Fletcher & Meldrum, 1968); and dimensions of the hard palate, (Carrell, 1936). None of these structural features were shown to have a consistent bearing on articulatory performance.
The possibility must remain however, that minor structural anomalies, particularly dental malocclusions and macroglossia, co-occurring with other predisposing factors in an individual child might well increase the difficulty the child experiences in speech sound acquisition.

The act of speaking must involve the monitoring of articulatory gestures via tactile and kinaesthetic feedback channels and therefore several investigations have examined oral perceptual abilities in relation to delayed and deviant speech sound development. Investigations such as Fairbanks,1954; McDonald,1964; McNeilage,1970 and Ringel,1973 centred on measurement of oral tactile sensitivity (two-point discrimination) and oral-form recognition (oral stereognosis). McDonald & Aungst (1970) demonstrated that oral form recognition improves with age throughout childhood and a study comparing oral perception abilities in oral and manual communicators (Bishop, Ringel & House (1973)) suggested that the development of oral perception may depend, at least in part, upon using the oral mechanism for speech activities. Investigations which have suggested a relationship between oral perceptual abilities and articulatory performance include Ringel (1970) who found a tendency for oral stereognosis errors to increase with severity of articulation disorder in primary school age children; and a study by McNutt (1977) which suggested that poor oral perceptual ability may be related to difficulties with the use of certain phonemes; (that is, he found that while children who misarticulated /r/ performed more poorly than other children on oral form recognition tasks, children who misarticulated /s/ did not).

A related area of research has investigated mature speech under conditions of temporary oral sensory deprivation induced by nerve-block anaesthesia. These experiments have involved normally speaking adult subjects and have shown that speech remains intelligible under the experimental conditions. However, when

acoustic characteristics of the speech are examined, (Horii, House, Li & Ringel 1973), changes can be identified relative to the subjects' normal speech.
It is not possible, of course, to make inferences about the effects of reduced oral sensitivity on developing speech from these experiments with mature speakers; but it is of interest that there is some evidence that speech sounds are selectively affected by sensory deprivation, with the production of consonant clusters, lingual fricatives and /l/ and /r/ most usually impaired, since these aspects of speech are characteristically non adult-like in child speakers with phonological disability.

Auditory as well as oral perceptual factors must also be involved in speech sound acquisition and there is a long tradition of investigating the auditory perceptual abilities of children with articulatory / phonological disabilities, and of training speech discrimination in therapy. Although phonologically delayed/disordered children have normal hearing for speech as measured by audiometric testing, they may have inadequate ability to discriminate and recognise speech sounds and/or inadequate ability to retain and recall sequences of speech sounds. It is widely accepted that in normal development perception of speech sound contrasts precedes production; that is, that most children correctly perceive the majority of the phonemic contrasts by around the age of 2 years, including contrasts which are neutralised in their own output forms (Hewlett,1990). However it cannot be assumed that phonologically delayed children also achieve complete, or almost complete perceptual development at the same early age.

Several aspects of auditory perceptual and processing abilities have been examined in relation to speech and language development: auditory discrimination for speech sound contrasts in general; perception of specific phonemic contrasts which are neutralised in output and auditory sequential memory for digits and sequences of phonemes. These are areas of investigation fraught with methodological difficulty and studies which purport to measure the same skills may use test procedures which place widely differing demands on subjects' abilities, (see Locke, 1980, for an evaluative review).

Examples of investigations of speech sound discrimination abilities include Locke & Goldstein (1971); Supple (1983); Lazarus (1988); Howell (1989); Broen & Jons (1978). Locke & Goldstein's study of phonemic production and perception in kindergarten children revealed only a "mild relationship" between children's production and perception of specific phonemic contexts in an identification task. An investigation of 4-year old phonologically delayed and normally developing children (Supple 1983) found no significant relationship between auditory discrimination scores and phonological ability, but did report a small positive relationship between "memory for phonemes" and articulatory ability. Lazarus (1988), in a study involving matched groups of normal and phonologically disordered children found that normally developing subjects were successful in discriminating contrasts which were neutralised in their own speech, while there was wide inter-subject variation in performance among the disordered subjects on the same task, with some disordered subjects performing well below normal levels, suggesting, perhaps a subgroup of children within the phonologically delayed category who have difficulties in this area. Improvement in auditory discrimination scores were shown to correlate highly with improvement in articulatory performance in a clinical study by Williams & McReynolds (1975). Howell (1989), however, found no differences between her phonologically delayed and normal child subjects on measures of auditory discrimination or auditory memory, but she does suggest, on the basis of subjects' performance on metalinguistic tasks (see below in this section) that different sensitivity and response to various acoustic parameters in a speech signal may underlie both metalinguistic (rhyming and segmentation) and phonological development.

Taken as whole these results are inconclusive, and while they suggest that some phonologically disordered children may have some difficulties in discriminating minimally distinct speech sounds, it seems unlikely, in view of the results of these studies, that auditory discrimination difficulties can be sufficient to account for their speech acquisition problems.

In a few studies of auditory discrimination abilities synthetic speech stimuli have been used and this may prove to be a fruitful line of investigation in the future. For example, an individual case study of a phonologically impaired pre-school child (Broen & Jons,1978) showed that although the child performed normally on a general test of auditory discrimination (Goldman-Fristoe_Woodcock Test of Auditory Discrimination, 1970), he performed less well on discrimination tasks, using synthetic speech materials, which focused on a specific individual perceptual cue which was relevant to a phonemic contrast neutralised in his output, (VOT in plosive consonants). Such use of synthetic speech materials may be able to shed light on the question of whether phonologically delayed children employ different perceptual strategies from normal children and perhaps assign different perceptual weight to acoustic cues in the speech signal. One such investigation in progress is Watson, (in preparation), 'A comparison of the auditory perceptual strategies used by phonologically disordered children and their normally developing peers'.

A further group of studies, for example, Yoss & Darley (1974) and Williams, Ingham & Rosenthal (1981), has investigated auditory sequential memory in speech disordered children using serial digit recall tasks such as the Auditory Sequential Memory subtest of the Illinois Test of Psycholinguistic Abilities (ITPA, Kirk, McCartney & Kirk, 1968), (Yoss & Darley, 1974; and Williams, Ingham & Rosenthal,1981). Results of such investigations have been inconclusive. The nature of the inter-relationship between performance on short-term memory tasks, such as digit recall, and speech abilities is uncertain. It may be that short-term memory utilizes some phonological image of the memorized items, in which case it might be expected that an association between level of speech sound acquisition and performance on serial recall tasks would be found. (For a discussion of this issue, see Bishop, 1988, p 232-235). Henry (1990) found significantly poorer performance on this sub-test of the ITPA in a group of 30 "severely speech-disordered" 3-5 year old children compared with a group of 60 normally developing children of similar age. Henry relates performance on this serial digit recall task to underlying rhythmic abilities which she also investigated in these children (see previous section).

In summary, investigations of auditory perceptual and processing abilities have not pointed with any degree of certainty to a causative relationship between these abilities and phonological disorder, although the possibility remains that auditory processing differences for speech sounds may be found between normal and phonologically disordered children.

Cognitive abilities must have a bearing on all aspects of language acquisition since language learning involves gradually deducing the rules of the target language through a process of hypothesis formulation, testing and revision. However with respect to the relationship between general cognitive ability and acquisition of the speech sound system the results of correlational studies are broadly in agreement that intelligence test scores (usually the Wechsler Intelligence Scale for Children (Wechsler, 1974) are not good predictors of level of articulatory performance. Everhart (1958) and Winitz (1959 a & b) found only weak positive correlations between scores on this test and scores on tests of articulation. In an earlier investigation, Reid (1947) concluded that articulation proficiency could not be predicted from intelligence scores when the IQ was measured as 70 or higher.

However, although broad based assessments of cognitive functioning may show no relationship to children's speech sound acquisition, it may be that specific metacognitive / metalinguistic abilities are related to this and other aspects of language acquisition. In recent years there has been a great deal of interest in the study of metalinguistic abilities in children. Metalinguistic awareness has been defined as "the ability to think about and reflect upon the nature and function of language" (Pratt & Grieve, 1984, p2), and is regarded as being manifested in skills such as monitoring ongoing utterances and making spontaneous speech repairs; young children's play with speech sounds and words; deliberate practise of sounds and words; ability to reflect on the structure of an utterance in order to make judgements about its acceptability or to perform operations upon it such as segmentation into words, syllables or segments. Phonemic synthesis and sound blending operations and ability to recognise and generate rhyming words are also considered to be skills dependent upon metalinguistic awareness since they involve reflecting on the structure rather than on the meaning of an utterance.

There have been a number of investigations of various aspects of metalinguistic awareness in children in recent years, but relatively few have been concerned specifically with phonologically disordered groups. Magnusson (1983) found that children with phonological problems, especially those with severe problems, had poor rhyming abilities compared with their normally developing peers and Howell (1989) compared groups of normally developing and phonologically delayed pre-school children on five tasks involving metalinguistic awareness and found significant differences between the subject groups on tasks involving rhyming and segmentation. This link between phonological development and development of the metalinguistic abilities underlying rhyming and segentation skills is further emphasised by the results of a study to evaluate the effectiveness of an approach to therapy for phonological disorder which centres on developing and utilizing metalinguistic awareness, (Howell & Dean, 1991). This study showed that the intervention procedure resulted in improvement in phonological performance beyond that expected from spontaneous developmental change, and that this improvement was associated with improvement on certain metalinguistic tasks, particularly involving segmentation skills, (Hill, Howell, Waters & Dean, 1989; Howell, Dean, Hill & Waters (in press). These findings suggest a link between phonological performance and performance on certain tasks which depend upon aspects of metalinguistic awareness, and that phonologically delayed children tend to have poorer metalinguistic awareness, in some respects, than normally developing children of similar age. However the direction of this relationship is not known; that is, it is possible that poor metalinguisitic abilities may contribute to difficulty in phonological acquisition, but is also possible that poor metalinguistic abilities (especially meta-phonological abilites which underlie awareness of rhyme and segmentation abilities) may be the result of delayed or deviant use of speech sounds.

There has been speculation that poor phonological/articulatory abilities in children may be linked to deprivation of speech stimulation at crucial times in development. It has been suggested that inadequate speech stimulation due to conductive hearing loss, associated with Otitis Media in early childhood, may cause persistent auditory processing problems leading to speech and language acquisition difficulties. This controversial issue is explored in Bamford & Saunders (1991) and Bishop & Edmundson (1986). Deprivation of speech stimulation may be due to environmental factors; however, the nature and frequency of verbal input necessary for normal speech development is unknown. Powers (1971) cites anecdotal evidence that children who have limited contact with adults, especially institutionalised children, may be slow in speech development. On the other hand, the phonological development of children of deaf parents has been found to resemble that of children from normal-hearing homes (Schiff-Myers, 1988).

A related factor may be the position of a child within a family: first born children and 'only' children have been found to have more advanced speech sound development at similar ages compared with children who have older siblings and, the wider the age difference between a child and his siblings, the better his articulatory performance, (Koch,1956). These findings might be related to the amount of linguistic stimulation available from parents and/or to the influence of conflicting pronunciation patterns from parents and older siblings which serve as models for the younger child.

This section together with the previous section has reviewed investigation of a variety of factors which have been considered to have possible relationship to phonological disability in children. None of these areas of study has produced conclusive results, however it seems that certain areas merit further investigation; in particular, the examination of auditory perceptual strategies in normal and phonologically disordered children using instrumental (synthetic speech) techniques may prove to be a fruitful line of research, as does the continued examination of the development of metalinguistic abilities in normal and phonologically disordered children. In addition, as stated at the end of section 1.3.2., the investigation of neuromotor control aspects of development in normal and phonologically delayed children has been given impetus by the results of acoustic analysis of adult and normal child speech which indicate that speech motor control develops gradually throughout childhood. Such investigations suggest that certain kinds of acoustic measures allow maturity of speech motor control to be compared across subject groups and therefore provide a means of assessing whether immaturity of speech motor abilities might be implicated in phonological disability. Studies which have attempted to compare motor control for speech in normal and speech and language disordered subjects are discussed in the following section.

1.4. INVESTIGATION OF SPEECH MOTOR CONTROL IN CHILDREN WITH SPEECH AND LANGUAGE DISORDERS

This section reviews the small group of previous studies which,like the investigation reported in this work, have used acoustic measurement to compare speech motor control in normal children and children with speech and language disabilities. The section also reviews studies which have used acoustic analysis and other instrumental techniques to examine perceptually non-adult-like speech segments, which result in loss of phonological contrast, in the speech output of phonologically delayed children.

The diversity of these studies in terms of subjects and methodology makes it difficult to integrate the findings, but taken together they point to the possibility that children with speech and language disorders may have poorer speech motor control abilities than normal children, and that this possibility is worthy of continued investigation.

An acoustic study by Stark & Tallal (1979) measured VOT and vowel durations in normal and in 'developmentally dysphasic' children. The description given of the subjects implies that they had some degree of phonological impairment as well as other language difficulties. Results showed that the language disordered children exhibited "lack of precise control over the temporal parameters measured as compared to a control group."

A further acoustic study by Weismer & Elbert (1982) focuses on temporal variability in repeated tokens of a particular 'misarticulated' speech segment. A group of 4 - 6 year old children who 'consistently misarticulated /s/' were found to exhibit greater segmental variability in their attempted productions of that sound than did a control group. Weismer & Elbert suggest that the obtained differences in variability may reflect differences in speech motor control capabilities between the two groups which may in turn underlie the experimental group's difficulties in achieving acceptable realisations of this speech segment.

An acoustic study of speech timing and variability by Catts & Jensen (1983) which involved subjects with a specific phonological disability is of particular interest in the context of the current investigation and will therefore be examined in more depth in the following chapter. The investigation involved several durational and temporal variability measures of multiple-token single-word (CVC) data and the authors conclude that the results suggest that some phonologically disordered children may have less mature speech timing control than normal children of the same age.

A series of studies by Amorosa and her colleagues in Munich has a rather different focus and examines a variety of aspects of fine motor co-ordination in children with speech and language deficits, (Amorosa,1982; Amorosa, von Benda, & Schaferskupper,1986; Amorosa, von Benda & Wagner, 1990). The first of these studies included investigation of timing variability in a hand co-ordination (tapping) task (see section 1.3.2. above), as well as variability of timing of segmental and suprasegmental features of speech and showed that a group of 'dysphasic' children were significantly more variable on durational measures involving both speech and hand co-ordination tasks. The two later studies focused particularly on measuring aspects of motor control of phonation in normal and language disordered subjects. The 24 disordered subjects aged between 5 and 8 years are described as having unintelligible speech, but some also had comprehension problems, 'dysgrammatism' and word-finding problems. There were 24 aged-matched control subjects. The two studies made auditory and acoustic analyses of subjects' voice production in 30 minute speech samples. Auditory analysis involved identifying instances of pre-utterance vocalisations; abnormal initiations; rough, breathy or tense voice; voice tremor; intraphonemic disruptions and pitch breaks. Acoustic (spectrographic) analysis was concerned with quantifying intrasyllabic pitch breaks and calculating mean fundamental frequency and a 'pitch perturbation factor' in syllable repetitions. The 1990 investigation was a follow-up study of 20 of the original experimental group of subjects.

Results showed that the language disordered children had "significantly more signs of abnormal prephonatory tuning and abnormal phonatory modulation than the control children". In particular the authors consider that the common occurrence of intraphonemic disruptions in phonation among the language disordered children is of significance since no such instances were found among the control subjects and the phenomenon is thought to be confined in normal development to children at the one and two-word stage of development, around the age of 1;6 - 2;6 years. Amorosa suggests that the results show that voice production in these children with unintelligible speech has "not yet become automatised" and indicate that "phonation, one of the systems of fine motor co-ordination contributing to speech production, is frequently disturbed in children with unintelligble speech". On the basis of the results of the follow-up investigation in which little improvement in phonatory control was found, particularly among the older disordered subjects, Amorosa argues that the "fine motor co-ordination problems manifest in voice problems are not due to a developmental delay in maturation but rather to abnormalities in the control of fine motor co-ordination resulting from some type of brain dysfunction.", and concludes that,

> The deficit in fine motor co-ordination as observed in voice problems can also be seen in articulatory and speech breathing problems and in fine motor co-ordination of the hands.
> (Amorosa et al, 1990, p.69)

Although the focus of Amorosa's studies is very different from the current investigation they add weight to the argument that speech motor development and spoken language development are inter-related and to the possibility that deficit in the fine motor co-ordination skills which underlie speech production may be implicated in children's speech disorders.

An acoustic study of compensatory speech abilities in normal and phonologically disordered children (Edwards J., 1991) is also of interest. The results of this investigation suggest that there are differences between normal and phonologically disordered children's abilities to produce vowel sounds under fixed jaw (bite-block) conditions, although the exact nature of this difference is not clear since the four disordered subjects did not exhibit consistent patterns of vowel production. If future investigations confirm and clarify differences between normal and phonologically disordered children's compensatory abilties this would be of great relevance to the issue of the relationship between development of speech motor control and phonological acquisition.

The remainder of the investigations reviewed in this section are concerned with acoustic and other instrumental measurement of particular target phonological contrasts in the output of speech delayed children.

Bond & Wilson (1980) measured voice onset times in voiced and voiceless initial plosive targets and vowel durations preceeding voiced and voiceless final plosive targets in a group of ten 'language disordered' children aged between 3;8 and 8;7 years and a control group matched to the experimental group for MLU. Results demonstrated that the language disordered children's control of the acoustic-phonetic detail of the voicing contrast was less mature than that of the control subjects; that is, the language disordered subjects gave indications of being at an earlier stage of acquisition of VOT values for voiced and voiceless initial stops, demonstrating greater degree of overlap in values between the two categories and greater variability than the normal children, and also exhibited more instances of prevoicing. The language disordered children also employed the vowel duration cue to the voiced/voiceless distinction in word final stops less consistently than the control subjects. Although interpretation of Bond & Wilson's study in relation to the current investigation is difficult because no indication of the nature of the subjects' language disorder is reported and, in particular, no information about their phonological development is given and no perceptual analysis of the children's productions of voiced and voiceless plosive targets is made, the results indicate that phonetic (speech motor) ability was less mature in a group of speech and langauge disordered children than in a control group.

Maxwell & Weismer (1982) studied VOT in a 'functionally misarticulating child' and found a subphonemic distinction between VOT values for voiced and voiceless plosive targets, a distinction which was apparently neutralised in the child's output. Such a finding implies that a phonetic (neuromotor) limitation underlay the child's apparent neutralisation of the voicing contrast rather than lack of 'phonological knowledge'.

Catts & Jensen's (1983) study, which has been mentioned above, involving speech disordered and normal children between the ages of 3;10 and 5;7 years demonstrated that the speech disordered subjects were at a phonetically earlier stage of acquisition of the voicing contrast for syllable initial stops than the normal children.

An interesting recent study (Tyler & Saxman, 1992) used acoustic analysis to compare development of the voicing contrast in three normally-developing children, aged 1:9 - 1;11 years, and in three older (3 - 5 year old) phonologically disordered children who were involved in treatment targeting the voicing contrast. It was found that the phonologically disordered subjects' patterns of acquisition did not replicate the normal pattern, being characterised by larger and more variable VOTs during the acquisition phase. Tyler & Saxman discuss possible reasons for the observed differences between the subject groups, including the possibility of differences in "skilled motor development", but do not reach any firm conclusions on the "nature of the interaction between perceptual, phonological and skilled motor development" (p.477).

Other investigations have provided evidence which suggests a motor immaturity explanation for other phonological neutralisations. For example, Catts & Kamhi (1984) showed, using acoustic analysis, that a child who reduced /s/+stop clusters to the stop only, was in fact making a distinction which was not perceptually salient to a listener; that is, the child consistently produced longer stop closures for /s/+stop targets compared with 'stop' only targets. This finding again suggests strongly that the child has phonological knowledge of the relevant contrast but lacks the neuromotor co-ordination and precision to realise the distiction in an adult way.

Weismer, Dinnsen & Elbert (1981) describe a study in which vowel durations were examined in three 'functionally misarticulating' children whose speech was characterised by the omission of word final stops. Two of the children were found to maintain the final voicing contrast through differential vowel duration similar to that which is found where final stops are realised normally. Weismer (1984) refers to such instances in which certain surface distinctions associated with a phonological contrast are maintained while others are not, as 'incomplete or partial neutralisation'. Such phenomena could be regarded as evidence of a phonetic (rather than entirely phonological) constraint on output forms.

This evidence from acoustic studies of incompletely neutralised phonological contrasts is supported by Gibbon (1990) who reports an investigation of yet another phonological contrast, in this case using electropalatographic data (EPG). Gibbon's study focused on the realisation of alveolar and velar stops in the speech of two speech impaired children; sisters aged 4;10 and 6;2 years. The younger sister was classified as having a moderate/ severe speech intelligibility problem while the elder sister was considered to have a severe speech dificulty. A number of simplifying phonological processes had been identified in the speech of both children. The elder child was able to distinguish overtly between alveolar and velar plosive targets in her output whereas the younger child was judged to consistently 'back' alveolar targets to velar place of articulation; that is, both alveolar and velar targets were perceived by listeners as velars. EPG analysis, which enables the stable contact and release phases of stop consonant production to be examined separately, revealed that although both children were making clearly distinguishable lingual/palatal contacts for the two places of articulation, the child who apparently neutralised the contrast seemed to be unable to "control the precise sequence of tongue movements necessary in the release phase of the two classes of stops." Specifically, the inability of the younger child to achieve an overt distinction between alveolar and velar stops appeared to be the result of difficulty in mastering the precisely timed sequence of events in the release phase of alveolar stop production in which the tongue body must be lowered in advance of the tongue tip, thus releasing the closure in the anterior region of the palate. Gibbon concludes that these findings imply that an essentially motor control, rather than a linguistic difficulty underlies the apparent neutralisation of the alveolar / velar contrast in the younger child.

The investigations reported in this section, although diverse in focus, methodology and criteria for inclusion of subjects, nevertheless, when considered together, provide evidence to support the view that relationship between speech motor development and phonological development and disability merits further investigation and may prove to be a fruitful line of enquiry in the search for explanation of delayed speech sound system acquisition in otherwise normally developing children.

1.5. NEUROLINGUISTIC AND NEUROPHYSIOLOGICAL ISSUES IN THE MOTOR IMPLEMENTATION OF SPEECH IN MATURE AND DEVELOPING SPEAKERS.

This section outlines some of the issues involved in constructing a model of the motor implementation of speech and relates them to the neurophysiological basis of speech production. The section includes discussion of the relationship between units of linguistic programming and units of motor planning; the theory of motor equivalence in relation to the specification of the goals or targets of the speech production mechanism; the specification of timing in speech production and the control of articulatory gestures. These issues are related where possible to what is known about the neurophysiological systems which underlie speech production and to discussion of how gradual neuromotor maturation and learning in childhood might expain observed differences in speech characteristics in young children and adults.

1.5.1. Neurolinguistic models of speech production.

There have been many attempts to construct models of the speech production mechanism (SPM), that is, models of the system through which abstract linguistic plans are 'translated' into overt spoken language.

A model of the SPM must attempt to address the following issues, (adapted from Daniloff, Schuckers & Feth 1980): it must specify the basic unit or units of linguistic planning which constitute the input to the SPM; specify the relationship between units of linguistic planning and units of motor planning and the nature of the goals or targets of the SPM; provide for a timing mechanism or mechanisms; account for how control is maintained over motor implementation as a linguistic plan is being executed and account for co-articulation phenomena. In addition it should attempt to integrate with what is known about the neurophysiology underlying speech production and attempt to account for developmental phenomena.

Daniloff, Schuckers & Feth review several models of speech production in the light of these requirements. For example, models proposed by Kozhevnikov & Chistovich (1965), Wickelgren (1969), Henke (1966), Ohman (1966), and MacNeilage (1970).
A model devised by Laver (1977) incorporates many features of earlier models and addresses many of the issues outlined above. Laver's model (figure 1 below) includes levels of linguistic programming, motor programming and neuromotor execution and emphasises the importance of both external feedback (after the speech event) and internal feedback (during speech activity) and provides for both feedforward and feedback connections between levels.

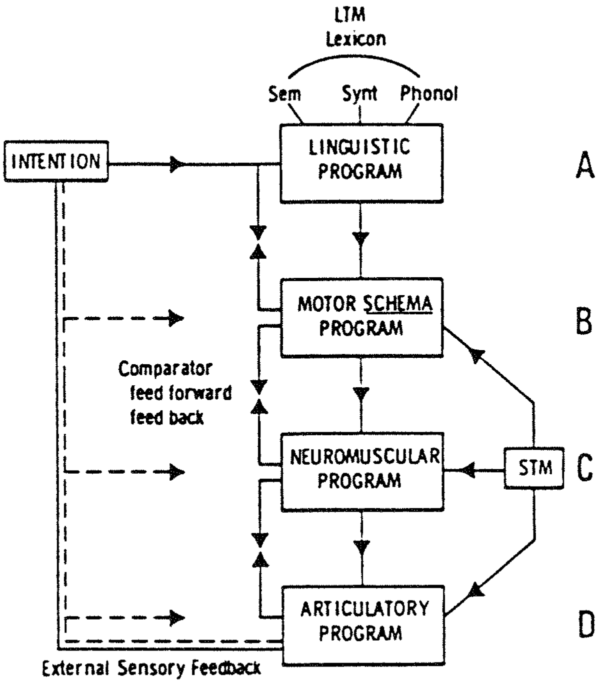

Figure 1. Model of speech production (after J.Laver,1977)
LTM = Long term memory; STM = Short term memory

The first stage in the model, (Level A) is the retrieval and selection of linguistic units in which semantic and grammatical information appropriate to the intended message is specified. The next level (B) is a stage of abstract motor planning or preparation of motor schemata which reflect the requirements of the linguistic programme. The following level (C) in the hierarchy involves the translation of the abstract motor schemata into actual neuromotor commands which will result in articulator movements (Level D). Laver's model incorporates a Short Term Memory buffer (STM) in which abstract motor schemata may be held, or 'stacked' prior to execution. It may be at this level that serial order errors occur. The model also incorporates external sensory feedback loops (tactile and auditory) which feed information back to all levels of the system and allow outcome to be compared with intention; and internal feedback and feed forward mechanisms which allow for on-going modifications at all levels.

A more recently proposed model of speech production (Hewlett, 1990) focuses on the production of single words and is particularly interesting in the context of the current investigation since it is able to account for developmental phenomena in speech acquisition.

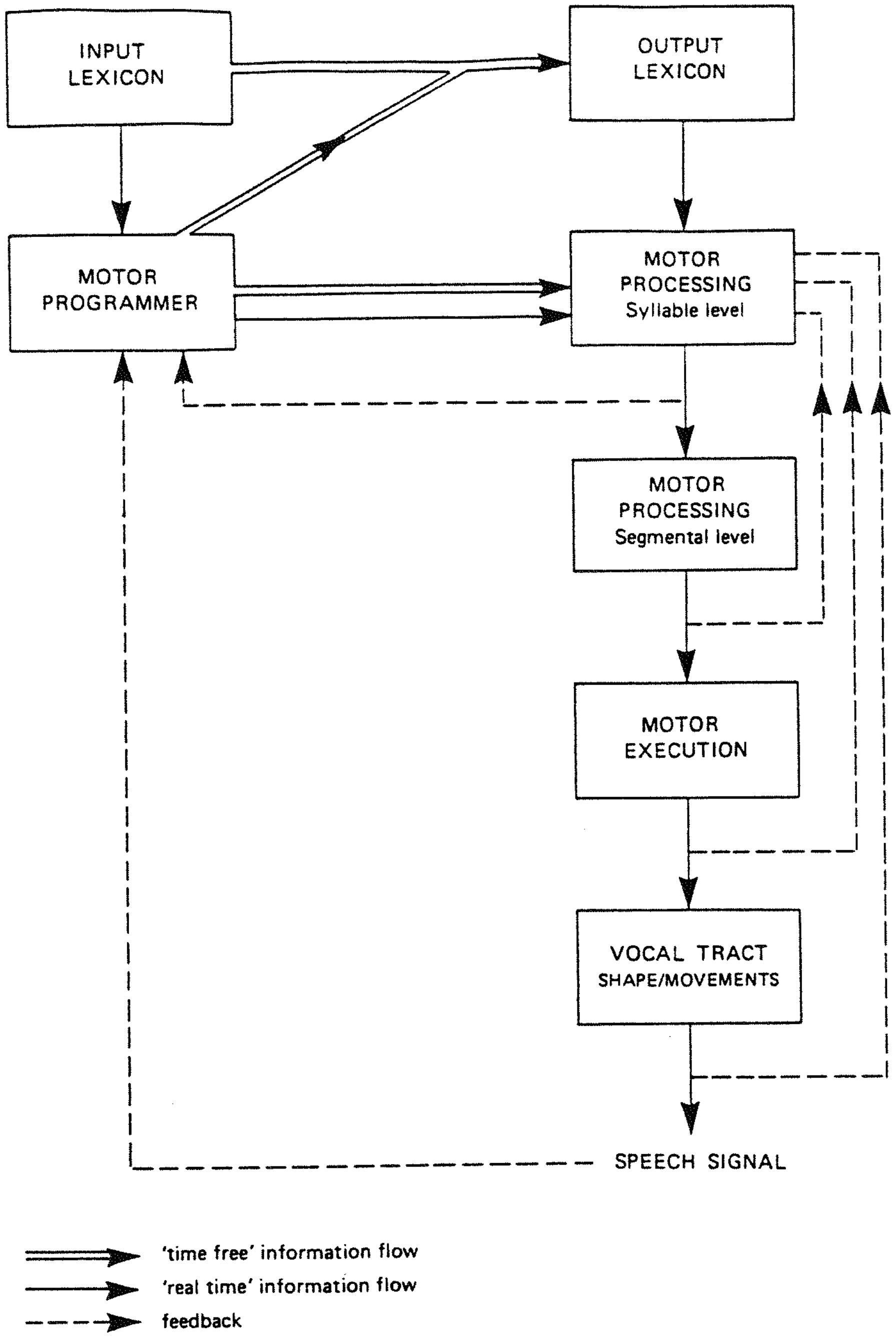

Figure 2. A model of speech production (after Hewlett 1990)

Hewlett's model includes both input and output lexical representations and provides for two alternative routes to the motor processing and lower levels of the mechanism. The first route involves the Motor Programmer which devises motor plans for the reproduction of perceptual targets received from the Input Lexicon; the motor programmer then passes the devised plan to the Motor Processing and Motor Execution components. When a plan for a lexical item is judged to be satisfactory, the articulatory feature specification is entered into the Output Lexicon and, on subsequent

occasions, the alternative, faster route from Output Lexicon direct to Motor Processing / Execution is employed. The model provides for both external and internal feedback between levels.
Hewlett's model is referred to in more detail in the final chapter of the thesis where it provides a provocative basis for the discussion of the results of the investigation.

1.5.1.1. Units of linguistic planning and motor planning.

Attempts to identify the nature and size of the basic linguistic units which 'drive' the SPM have been a major focus of speech production research. Speech error data have made an important contribution to the discussion; that is, the fact that mistakes are often identified in the serial ordering of speech sounds implies that the phoneme/segment may well be the smallest, independently manipulable element of language. There is not, however, universal agreement on this point: Kozhevnikov and Chistovich (1975), for example, argue for the syllable as the basic unit of both speech timing and coarticulation. Shattuck-Hufnagel (1979) suggests that lexical items may be stored complete in abstract form, but that during production, a process of 'phonological scanning copying' takes place while the lexical item is held in a short term memory store which could account for serial order errors. The fact that sound sequencing errors can span up to 3 or 4 words implies that at some point in the process of speaking a large chunk of speech is preplanned as a single unit and held in storage prior to articulation and evidence from studies of co-articulation support this notion; since co-articulation may spread 3 or 4 phonemes in advance of, or subsequent to, the segment which is the 'source' of the co-articulation and may spread across word boundaries, the speaker must be holding as many as several words in storage so that co-articulated gestures can be planned.
Halliday (1963) suggests that the most likely unit of linguistic planning is the tone group, that is, a stretch of speech of about 7 or 8 syllables containing one prominent nuclear syllable on which change of pitch occurs. The idea of the tone group as corresponding to a unit of neurolinguistic planning is consistent with prosodic features of rhythm, intonation and stress being part of the plan at this stage.

The nature of the relationship between units of linguistic planning and units of motor planning has been the subject of much speculation. The traditional 19th Century view of voluntary motor activity was that all neuromotor commands originated in complete form in the motor cortex of the cerebral hemispheres (see section 1.5.2. below). That is, in this view it was asserted that a direct one-to-one correspondence existed between a particular pattern of cortical excitation and a particular movement. However such a system, in the context of the motor implementation of speech, would place an impossible burden on the motor cortex: a single speech segment may involve as many as 35 different muscles (Hardcastle, 1976) and a single phoneme will vary in relation to neighbouring sounds and in relation to its position in the utterance (allophonic variation and co-articulation). If the 'one set of commands to one sound' theory were correct, the cerebral cortex would have to store an impossibly large number of separate motor commands specifying each one of these different allophonic and co-articulated variations.

A relatively recent and influential suggestion was that each abstract phoneme is specified by a single set of invariant motor commands, at cortical and subcortical levels, (Liberman, Cooper, Schankweiler & Studdard-Kennedy, 1967). That is, each context-free abstract linguistic unit (phoneme) is specified in the SPM by a set of invariant neural commands. In such a model allophonic variations and casual speech forms are considered to be due to " mechanical and neuromuscular limitations of the speech production apparatus and temporal overlap in commands" (MacNeilage, 1972, p 40). However if all allophonic and co-articulated variations have to be regarded as consequences of the mechanical and neurophysiological limitations of the speech production apparatus or due to the temporal overlap of commmands, all languages should demonstrate similar types of allophonic variations and similar co-articulatory characteristics. This is not the case. Furthermore, electromyelogram studies which measure electrical activity in muscle tissue show that the motor commands reaching the speech musculature are context dependent (MacNeilage, 1972).

Any theory of the relationship between units of linguistic planning and units of motor programming and execution must allow for the fact that the movements which result in a particular phoneme must have different starting points and therefore involve different extents and directions of movement depending upon the identity of foregoing segments; and must also account for the observation that the orofacial musculature is able to execute speech under a variety of conditions. Evidence of speakers' abilities to articulate clearly in a variety of circumstances, for example while holding a pipe between the teeth or a cigarette between the lips (Abbs & Kennedy, 1982), and the fact that the respiratory and phonatory systems are able to continue to perform their required speech production functions while movements of the the torso, head and arms are simultaneoulsy carried out with consequent profound influences on the muscle contractions required, suggest that speech motor commands are not invariant muscle by muscle instructions but rather they are adjustable to assure that individual articulators reach semi-invariant target positions despite variations in their starting positions from one occasion to the next.

MacNeilage (1970), following the theory of Hebb (1949), suggested an explanation for these observations which has had a lasting influence on subsequent theories of speech production. This explanation, the theory of motor equivalence, proposes that as any motor activity is learned, information from the relevant sensory modalities (auditory, visual, tactile, proprioceptive) is integrated to build up a schema of movement directed towards reaching a particular goal or target. MacNeilage (1970) suggested that the goals or targets of the SPM could be, "points specified within an internalized space co-ordinate system of the kind that Lashley (1951) considered to underlie all movement control", and supports this suggestion by arguing that since visual-motor co-ordination depends upon an "abstract conception of space", as witnessed, for example, by a skilled tennis player who is able to accurately direct a ball to a particular part of the court no matter how fast or from what direction the ball approaches his racket, then auditory-motor co-ordination may be similarly directed.

Experiments which analyse speakers' productions when holding bite-blocks between the teeth have been referred to in section 1.1.4. above, (for example, Lindblom, Lubker & Gay, 1979 and Fowler & Turvey, 1980). Such investigations have shown that mature speakers are able to compensate for the block immediately and achieve accurate vowel formant frequencies and thus support MacNeilage's theory. Other experiments examining speakers compensation for some impediment to normal movement have shown that the articulators may adopt positions different from those usually associated with the particular phoneme in question; for example, in Folkins & Abbs (1975) investigation in which jaw elevation associated with bilabial stop closure was unpredictably impeded, compensation was achieved by a lowering of the upper lip. This kind of evidence suggests that the goals or targets of articulatory movement may not necessarily be specified in terms of absolute space, but perhaps in terms of achieving contact between articulators or in terms of achieving adequate intra-oral pressure.

It is also likely that, to some extent at least, the goals for speech production are specified as auditory targets, since mature speakers seem to have the ability to achieve a required auditory effect using an articulatory configuration entirely different from their usual production when circumstances demand. For example, in an experiment (Riordan, 1977) in which speakers attempting rounded vowel targets were prevented from achieving lip-rounding it was found that subjects achieved the required auditory effect, that is, the required formant frequencies, by lowering the larynx, thus producing lengthening of the vocal tract to compensate for their inability to lengthen the tract by rounding the lips.

In section 1.1.4. several investigations of children's articulatory compensatory ability were discussed which have indicated that young children are less able to compensate for impediments to normal articulation than adult speakers. This implies that 'motor equivalence' for speech develops gradually, presumably as a result of both maturation of underlying neuromotor and sensory feedback systems and of trial and error learning.

Folkins & Bleile (1990) suggest a radical extension of the idea of 'motor equivalence' for speech. In their view, the "processes of the motor system are organised so that control is integrated across the various perceptual requirements" of the speech message. In this 'integrated motor approach' it is argued that speech motor strategies are organised, not to achieve a serially ordered set of linguisitc unit targets, such as phonemes or syllables, but to "produce the speech message as a larger, holistic behaviour" (Folkins & Bleile, 1990, p 605). That is, in this view, the goal of the SPM is the 'holisitc' production of an intended message rather than the achievement of a series of specific spatial or perceptual targets, and therefore, many combinations of activity, at several levels, may be employed to transmit the same message. If this view is correct, then children's task in speech acquisition must, presumably, involve experimentation and sensori-motor exploration through which they gradually discover which combinations of gestures are permissable, or successful, and which are not permissable in implementing an intended message.

1.5.1.2. Control of articulatory gestures.

In the motor equivalence view of speech production, the abstract, spatial / temporal / acoustic goals of the motor planning stage are converted into neuromotor commands which bring about the required configurations of the vocal tract. These neuromotor commands are under the influence of both open and closed loop control systems. Open-loop control mechanisms preset commands necessary to achieve a particular target under a variety of conditions, and closed-loop (or servosystem) control systems allow for on-going adjustment during the course of an action under the influence of feedback from proprioceptive, tactile and auditory receptors (see section 1.5.2., below, for an overview of the neurophysiology of these feedback and control mechanisms). The control mechanisms which govern the implementation of motor schemata are dispersed throughout all the structures which play a part in achieving a particular action and it is thought that the control systems in various structures of the articulatory apparatus are organised as a series of layered levels, (Abbs 1979). Such organisation allows for compensation between levels and thus contributes to 'motor equivalence' and to the flexibility and adaptability of the speech production mechanism.

A general theory of movement known as Action Theory, which originated in the work of Bernstein (1967) has been applied to speech production by authors such as Greene (1972), Turvey, Shaw & Mace (1979) and Fowler, Rubin, Remez & Turvey (1980).The central concept of Action Theory is that of 'co-ordinative structures'; that is, "a group of muscles, often spanning several joints, that are constrained to act as a unit" (Turvey et al, 1979, p 563). That is, a co-ordinative structure is an organisation of muscles, or muscle synergism, which

produces actions of a certain defined kind. Co-ordinative structures are regarded as being the result of the action of reflex neural circuits referred to as 'tunings'. The primary source of this tuning is thought to be through proprioceptive feedback channels.
Co-ordinative structures are said to be embedded; that is, structures concerned with fine-grained movement are 'nested' within more coarse grained-structures. The actions produced by co-ordinative structures or muscle synergisms are often cyclical in nature, that is, when a structure has performed its 'repertoire' of action once, the sequence is automatically begun again, for example as in walking, chewing, breathing. Perhaps, if these theories apply to speech production, vowel production may be similarly cyclical in nature.

Fowler proposes that co-ordinative structures involved in speech production involve both voluntary and involuntary (automatic components) and that these synergisms operate at all levels of the speech production process; respiratory, laryngeal and supra-laryngeal. For example, the muscles of inspiration and expiration form a synergism or co-ordinative structure whose task is to control subglottal pressure. Subsynergisms are embedded within these main co-ordinative structures, for example, there may be a sub-synergism concerned with co-ordinating the actions of tongue body and lips (Kent & Netsell, 1971). Fowler also presents some evidence to suggest that these three main synergisms may be further grouped to form even larger scale co-ordinative structures; for example, a co-ordinative structure involving lips, jaw, hyoid bone and larynx may be involved in the action of lengthening the vocal tract. Such a synergism of muscle groups would help to explain the results of the experiment by Riordan (1977) cited above. Fowler et al argue that both temporal and spatial aspects of articulatory action are a direct consequence of these embedded systems of co-ordinative structures.

1.5.1.3. The specification of timing in speech production.

It has usually been supposed that interaction of two components is involved in the specification of timing relationships in a stream of speech, (MacNeilage, 1980). The first is a component through which the language specific aspects of the relative timings of speech segments are specified; for example, specification of short versus long lag voice onset in stop consonants and specifications for inherently long and short vowels in various phonetic contexts. The temporal overlap of coarticulated segements might also be specified by this component. The second component is one which regulates the absolute durations of segments in relation to aspects of an utterance such as speaking rate and utterance length and stress.

The effects of these non-segmental parameters on segmental timing have been the subject of many investigations the results of which have contradicted what is, perhaps, the intuitive expectation of a "Horizontal time compression mechanism" (Gay ,1981) in which all segmental durations would be expected to be proportionately reduced in response to factors which affect segment length.

For example,a series of investigations on Swedish by Lindblom, Lyberg & Holmgren (1977), reported in MacNeilage (1980), showed that segments were shorter in duration in longer utterances, but that the relationship between utterance length and segmental durations was not straightforward. That is, vowels were found to be more susceptible to shortening than consonants, and amount of shortening depended on both the length of utterance which preceeded a measured segment, and on the length of utterance which followed a measured segment with the number of succeeding syllables having more influence than the number of preceeding syllables.

Lindblom's experiments also showed that shortening of segments in unstressed contexts is not uniform across segment categories, with vowels more affected than consonants, and tending to be 'undershot' in articulatory placement. It is possible that this undershoot is simply a consequence of reduced duration, that is, the articulators do not have the time to achieve their usual target positions and target undershoot is 'tolerated' by the speech control mechanisms in unstressed contexts; or, it may be that different targets are set in unstressed contexts and different organisations of muscle activity apply.

Experiments involving manipulation of speaking rate have also shown that vowel durations are compressed to a greater proportional extent than consonant durations in fast rates of speech; for example, Gay (1978), showed that vowel durations were compressed more than consonant closure durations. That is, in an electromyographic investigation, at increased speaking rates activity is higher in muscles involved in the consonantal portions of an utterance, but lower in muscles involved in vowel production.

These different rate effects on vowel and consonant production suggest a possible dichotomy between vowel and consonant production, (Ohman, 1966; MacNeilage & Davis, 1990; Fujimura, Erickson & Wilhelms, 1991), and this possibility is explored below (section 1.6.).

A number of other investigations involving experimental manipulation of speaking rate have indicated that a variety of strategies are available to speakers when faced with the task of producing an utterance at faster than habitual rates. For example, in Linblom's experiments and also in investigations by Kuehn & Moll (1976) in which articulator movements were monitored at various speaking rates, some subjects displayed considerable target undershoot at increased speaking rates, whereas other subjects did not; rather these speakers were able to adapt the velocities of their articulatory gestures and achieve usual target positions at increased rates. MacNeilage suggests that these two different responses to instructions to speak at faster rates may depend upon "the subject's tacit assumptions about the need to speak precisely or to communicate clearly in the experimental situation" (MacNeilage, 1980 p 15).
Gay also found that in some instances vowel undershoot did occur during fast rates of speech and in other instances did not. He suggests that the occurrence of target undershoot may be dependent on vowel identity, stress, language differences and individual differences.
Kuehn and Moll (1976) demonstrated 'trade-off' between velocity and extent of movement in vowel production at different speaking rates which varied between speakers. That is, some speakers maintained the same velocity and decreased the extent of movement displacement and others increased articulator velocity and exhibited little target undershoot. Gay also demonstrated greater degrees of temporal overlap between consonants and vowels at faster speaking rates, and that some speakers seem to 'cope' with the demands of fast speaking rates chiefly by "reordering the relative timing of sucessive gestures rather than by decreasing durations of individual segmental units" (Gay, 1981, p 157).

Thus, relationship between speaking rate and the temporal and spatial characteristics of individual segments in mature adult speech seems to be complex and to vary between individuals. Presumably different speakers learn to employ different strategies either by chance or as a result of the particular strengths and weaknesses of their motor speech abilities. Indeed, there is likely to be a great deal of individual variation in level of speech motor skill among mature speakers just as there is among mature individuals who engage in any other motor activity. Perhaps, for any indivdual speaker there is an optimum rate of utterance at which the SPM is best able to fulfil its task of achieving articulatory/acoustic targets, and mature speakers have learned to adopt this optimum tempo in most communicative contexts. When instructed to adopt non-habitual, faster rates some speakers may have the speech motor facility to increase articulator velocities in order to maintain accurate target seeking behaviour whereas other speakers have to adopt other strategies which include tolerance of target undershoot.

If such an argument is accepted it follows that one of the tasks facing children during speech acquisition is to 'discover' and achieve control over an optimum speaking rate within the limitations of their current speech neuromotor abilities and to devise (and revise) strategies for achieving articulatory gestures which will result in acceptable output forms in a variety of conditions of utterance length, stress conditions and rate of utterance. This issue is discussed further in the final chapter of the thesis in the light of the results of the current investigation.

(A further group of studies which refer to the relationship between speaking rate and temporal variability in mature and developing speakers are of particular relevance to the current investigation and are reviewed in Chapter Two.)

How are these various speech timing characteristics explained? Traditionally the spatial/acoustic targets of the speech production mechanism (discrete segments, feature bundles, canonical forms) have been regarded as being essentially timeless. In such 'extrinsic' theory of speech timing, for example, Daniloff & Hammarberg (1973) and Hammarberg (1976), it is assumed that the plan for an utterance does not specify time, and the plan must be 'translated' into a continuous, overlapping series of articulatory gestures in which the features of these discrete segments are spread to adjacent segments. However, more recently, 'intrinsic' theories of speech timing based on Action Theory (Bernstein,1967) have gained influence. As discussed briefly above, Action Theory as applied to speech production regards all articulatory movements and the timing of those movements as a direct outcome of the action of embedded sets of co-ordinative structures of muscle synergisms. Such theories argue that,

> Time evolves from the 'playing out' of the dynamics (of articulatory gestures), but there is no programming, time control, or time representation anywhere.
>
> (Kelso & Tuller, 1987, p 211)

The essential difference between extrinsic and intrinsic views of speech timing are summarized by Bell-Berti & Harris (1981).

> Existing models of speech production and co-articulation have failed to account for observations of real speech because they have considered timing as a by-product of articulatory events instead of an integral organising parameter of the speech motor plan",
>
> an alternative type of model is proposed which,
>
> "....considers time and timing relationships to be intrinsic to speech motor organisation and the units of speech to be inherently dynamic gestures rather than static vocal tract configurations.
>
> (Bell-Berti & Harris, 1981, p 9)

Furthermore, in such a model, consonants and vowels are seen as the result of two distinct kinds of activity brought about by distinct co-ordinative structures. Vowels are viewed as being characterised by relatively slow cyclical changes in the global shape of the vocal tract, and the production of consonants is the result of separate co-ordinative structures whose action is imposed on a background of continuous vowel production. Thus vowels and consonants, all of which include the dimension of time in their specification, are co-produced and the apparent spreading of features between adjacent segments is viewed as the overlapping of 4-dimensional segments. Such co-production of vowel and consonant segments is made feasible be positing that the two classes of speech sound are products of different co-ordinative structures which result in qualitatively different kinds of actions, which are therefore perceived as discrete even though they overlap in time. These suggestions certainly seem to offer a possible explanation for the different rate effects on vowel and consonant production discussed above and the continuous cyclical production of vowels would seem to be compatible with the stress and rhythmic characteristics of speech.

Such a dichotomy between vowel and consonant production has been proposed in the past; for example, Ohman (1967), proposed a model of speech production which emphasised the 'carrier nature' of continuous vowel production brought about by relatively slow and steady co-ordinated action of the tongue, lips and jaw from one vowel to the next and "upon this steadily shifting vowel movement are superimposed the sharp consonantal modifications". Consonant-vowel co-articulation arises from the superimposition of consonantal gestures on the continuing vowel to vowel movement base. Ohman's proposition would seem to anticipate the notion of distinct sets of co-ordinative structures underlying two qualitatively distinct kinds of movement in vowel and consonant production.
For a recent exposition of such view of the temporal organisation of articulatory gestures using a computational model, see Fujimura, Erickson & Wilhelms (1991). MacNeilage & Davis (1990) propose a "Frame/Content" view of speech motor control which is also compatible with the notion of different sets of co-ordinative structures underlying vowel and consonant production. MacNeilage & Davis discuss their model primarily in the context of the early stages of speech development, arguing that rhythmic syllable-like vowel to vowel vocalisations are the precursor of speech in both an individual and an evolutionary sense. This model which has considerable relevance to the question of the inter-relationship between neuromotor maturation and speech acquisition is discussed in more detail in section 1.6. below.

1.5.2. Neurophysiological basis of speech production.

This sub-section describes in outline the neurophysiological systems which underlie the motor implementation of speech in mature adult speakers with reference to the possible relationship between gradual refinement and integration of these systems during childhood and the observed development of speech motor control abilities.

As in any other co-ordinated voluntary motor activity, the production and control of speech involves the integrated functions of many motor

and sensory components of both the central nervous system (CNS) and peripheral nervous system (PNS). That is, "the nervous system has an enormous repertoire of functional processes with which to formulate, regulate and co-ordinate the multiple gestures of human speech" (Abbs & Kennedy, 1982, p 84). The following basic requirements must be fulfilled by the nervous system in the performance of voluntary movement: (i) the appropriate muscles must be selected;
(ii) each participating muscle must be activated or inactivated in proper temporal relation to the others and (iii) the appropriate amount of excitation or inhibition must be exerted on each muscle (DeLong, 1971, cited by Abbs & Kennedy, 1982, p 86).
These processes of muscle selection, activation, regulation and excitation/inhibition are thought to be "played out over descending neural pathways from a motor tape-like schema established through extended learning and experience" (Abbs & Kennedy, 1982, p 86). However, if the phenomenon of motor equivalence is to be accounted for, these descending patterns must be modified and refined at one or more levels of motor execution in order to fit continuously changing conditions.

1.5.2.1. The Central Nervous system in speech production.

The topographic organisation of speech and language functions at cortical level has been much studied over a long period. Evidence has come traditionally from studies of disruption of linguistic functioning in patients with circumscribed lesions of brain tissue, (Penfield & Roberts, 1959); studies of 'split-brain' patients (Zaidel, 1978) as well as from studies involving cortical stimulation and in more recent times from investigation using brain scan and blood flow monitoring (Lassen, Ingvar & Skinhof, 1978, cited in Edwards M., 1984).

It is widely accepted that the dominant hemisphere is specialised for language functions and for the control of fine rapid movements such as are required in speech. Investigations of 'split brain' patients have shown that the dominant hemisphere is superior in both the perception and production of phonological units - that is, in segmental aspects of speech perception and production, (Edwards M., 1984). However some of the non-segmental, prosodic aspects of speech production, especially those associated with affect, such as pitch and loudness, may be controlled by the non-dominant hemisphere.

Comparative studies of cortical anatomy and physiology in lower mammals and in higher primates including man demonstrate that the human cortex is particularly well equiped to serve speech functions (Keller, 1987). That is, the frontal lobe is significantly more developed in man than in other mammals and has undergone a much greater separation and specialisation of motor and sensory representations while retaining sufficient overlap of motor and sensory components to allow for integration and control of movement. In humans there is also increased direct cortical innervation of the peripheral musculature, with an associated increase of fine motor control over separate body parts; an evolutionary development known as "fractionation of movement", (Ghez, 1981, in Keller, 1987). There is also evidence that a much greater proportion of the human primary motor cortex compared to other primates is devoted to direct innervation of the vocal tract, allowing for the fine motor control required in speech motor processing.

Figure 3 (after Edwards M., 1984), shows the areas of the left (or dominant) hemisphere known to be associated with speech and language.

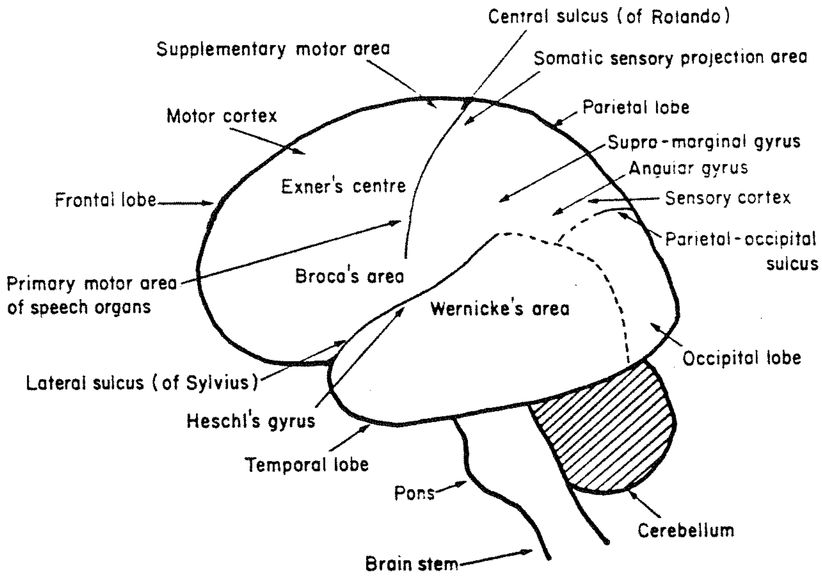

Figure 3. The lateral surface of the left cerebral hemisphere (in a right handed person) showing some of the main structural parts and positions of the various 'speech centres'.

The primary motor area (Motor Cortex in figure 3) of the frontal lobe (usually defined as Brodman's Area 4) is somotopically organised and neural instructions which are concerned with articulatory movements originate in the inferior portion of this area immediately above the Sylvan fissure. Evidence from stimulation studies suggests that the primary speech motor cortex may be concerned with muscle commands affecting a single 'speech valve' (Keller, 1987); that is, a "functionally defined synergistic muscular unit, such as those controlling the laryngeal, velo-pharyngeal, lingo-palatal and labial ports", Keller, 1987, p 141).

In contrast, the other (secondary) speech motor cortical areas, including the Pre-Motor cortex, the Supplementary Motor Area and Broca's Area, are thought to be more directly concerned with the organisation of movements across the whole of the speech musculature; that is with units at the "phonemic and higher (syllabic) levels of phonological organisation" (Keller,1987, p 142). These areas of the cortex are thought to be concerned with the development of motor skills of more complex character than those represented in the primary motor cortex (Gatz, 1966), and to be involved in the ordering and sequential aspects of speech production.

Abbs & Welt (1985) draw particular attention to the vital role of sensory input to the motor cortex in the organisation and control of movement. They state that as well as relatively indirect visual, auditory and vestibular input to the motor cortex there is also considerable and much more direct (short latency) input from somatic sensory afferents, suggesting that input from deep somatic structures plays a "feedback role for moderating the output of efferent zones" (Abbs & Welt p164). It may be, therefore, that the areas traditionally regarded as the motor cortex are better regarded as performing overlapping motor and sensory functions, that is, integrational functions. The descending neural pathways from the motor cortex, the pyramidal and extra-pyramidal tracts (see figure 4, below) have also traditionally been regarded as purely motor in function, but more recent investigators, for example Brodal (1981), cited in Edwards M., 1987, p 12, have argued that they also exercise influence over the ascending sensory information travelling to the cortex.

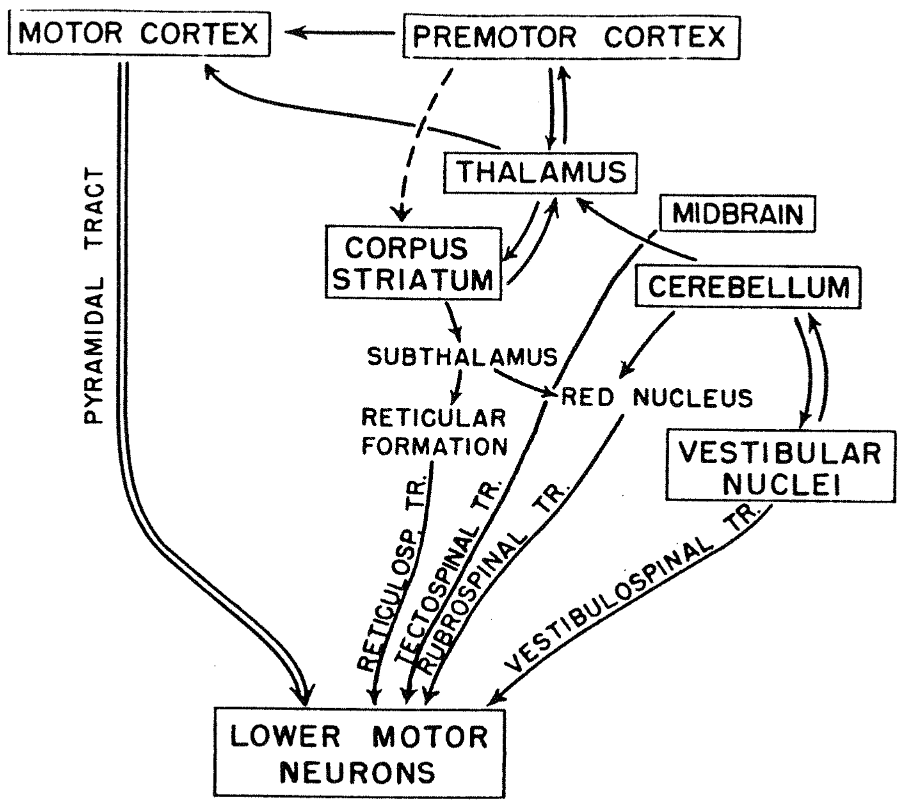

Figure 4. Schematic diagram of the pyramidal and extra-pyramidal systems (after Gatz 1966)

Fibres of the pyramidal tracts originate in the primary motor area of the cortex and in the premotor cortex, the supplementary motor area and also in the somesthetic cortex in the parietal lobe, allowing for the integration of sensory information in the control of voluntary movement. The Upper Motor Neurones in the pyramidal system consist of two fibre tracts: the cortico-spinal tract and the cortico-bulbar tract. The former descends from the cerebral cortex to the spinal cord where the neurones synapse with the cell bodies of Lower Motor Neurones. This tract gives off many collateral branches which connect with the corpus striatum, the nuclei of the pons, areas of the mid-brain and also branches which relay back to the cortex, indicating the complexity and degree of integration involved in the control of voluntary movement. The cortico-bulbar tract diverges from the cortico-spinal tract at the level of the mid-brain and its fibres terminate in the brain stem on voluntary motor nuclei of cranial nerves (see below).

The extra-pyramidal system is an immensely complex inter-related system of neural structures which includes the corpus striatum and the subthalamus together with connections to the thalamus, the red nucleus and the reticular formation. The descending tracts from this group of structures is known to have regulatory influence on movement and is especially well developed in man where it plays an important role in the motor control of speech.
The thalamus itself, as well as having descending connections which form part of the extrapyramidal motor system also has ascending connections with the cortex, and serves as a station in which all types of afferent information are integrated and relayed to the cerebral cortex. Thalamic dysfunction has been associated with dysphasic language disturbances, but dysarthric-type disturbances are also known to follow thalamic lesions, reflecting its importance in the control of speech motor behaviour. Edwards M. (1984) states that,

> The lateral ventral nucleus (of the thalamus) in particular may influence non-segmental aspects of speech relating to timing and ordering as well as to phonatory and resonatory parameters. (p 18)

The reticular nuclei of the medulla oblongata and pons and the red nucleus of the mid-brain have many input and output connections with the basal ganglia, the motor nuclei of the cranial nerves, the spinal cord and with the cerebellum. These areas are thought to be involved in the control of discrete movement and in maintaining appropriate levels of muscle tension throughout the body including in the vocal tract.

The cerebellum, which lies in the posterior cranial fossa and is attached to the pons, medulla and the mid-brain, through its "multiplicity of connections is able to exert influence on almost any part of the brain", (Brodal, 1981, cited in Edwards M., 1984, p 18). It is a key structure in a number of feedback circuits and is chiefly concerned with the programming and control of movement, rather than with its initiation. Voluntary movements after cerebellar lesions tend to be clumsy and to lack integration and organisation. It is therefore thought that the cerebellum acts as a "tuner and a modifier of motor schemata" (Edwards M., p 18); that is, it co-ordinates the action of muscle groups and times their interactions so that movements are performed smoothly and accurately. It therefore plays a crucial role in the timing of sequential rhythmic actions such as are involved in speech production.

The gradual development in the early years of life of the cerebellum as the seat of automatic control of movement is emphasised by Eccles (1973) who states that "throughout life, and particularly in the early years, we are engaged in an incessant teaching programme for the cerebellum". It is likely that such a process of gradual maturation and learning occurs in relation to the functional integration of all the central nervous system structures mentioned above and underlies the gradual development of children's motor speech abilities.

1.5.2.2. The peripheral nervous system in speech production.

The speech musculature is under the influence of cranial nerves (see figure 5), most of which consist of both efferent (motor) and afferent (sensory) fibres. Cranial nerves V (trigeminal), VII (facial), IX (glossopharyngeal), X (vagus) and XII (hypoglossal) are those most directly involved in speech. In addition the nerves of respiration form a component of the system and the VIIIth cranial nerve (acoustic / vestibular) is essential in the development and maintainance of speech.

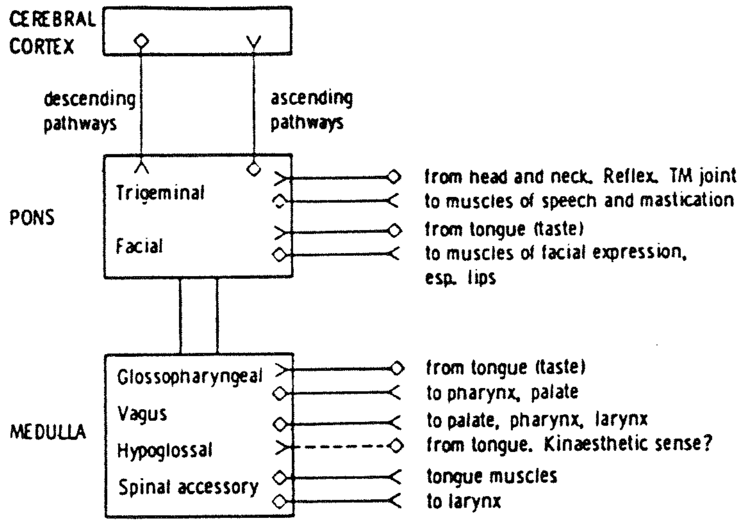

Figure 5. Schematic representation of the peripheral nervous system concerned with speech production (after Edwards M., 1984, p 29)

Efferent components of cranial nerves transmit neural commands from the CNS to the striated (voluntary) muscles involved in speech and afferent components transmit back to the CNS information derived from receptor organs in the skin, mucosa and muscles of the articulatory apparatus. As many as 35 different muscles may be involved in articulatory movements of the mandible, tongue, lips, velum and pharynx for each speech segment produced, (Hardcastle 1976). The muscles of articulation are able to perform extremely rapid, smooth and precisely targeted movements. Several factors contribute to this ability: firstly, the high innervation ratios in all the musculature involved in articulation compared with areas of the body where only more gross movements occur; secondly the gradual, phased involvement of motor units resulting from different thresholds of excitation of motor neurones and different velocities of neural transmission in the neurones supplying the speech musculature.

The velocity with which neural impulses are transmitted through nerve fibres is a function of fibre diameter, fibre length and the transmitting properties of the myelin sheath which surrounds the fibre. Hardcastle (1976, p.7) suggests that the relative latencies of cranial nerve fibres supplying the various parts of the articulatory musculature may have an important bearing on the temporal ordering of articulatory gestures during speech.

The characteristics of the transmission of neural impulses across synaptic junctions between nerve cells are important in explaining aspects of mature speech motor performance.
Transmission of a neural impulse across a synaptic junction requires a certain level of electrical discharge which can only be attained when impulses from several neurones impinge simultaneously on the synapse. This requirement results in a system of neural transmission in which any one neural command is constantly open to modification under the influence of neighbouring neurones. Furthermore, not all neurones facilitate the passage of impulses across synaptic junctions; some are inhibitory in effect. Under the influence of a number of incoming impulses, a post-synaptic neurone must sum the opposing synaptic effects and can fire only when its net excitation exceeds the critical level. Such a system results in great flexibility and adaptability since, under the control of the CNS, movements can be "continually modulated and varied according to prevailing conditions" (Hardcastle, 1976), and must be an important factor in the ability to adjust articulatory gestures in order to achieve particular acoustic/spatial targets in a variety of circumstances, (motor equivalence).

A further characteristic of synaptic transmission is relevant to the motor implementation of speech. It has been shown that when a neural impulse has been allowed to cross a synaptic junction, the threshold for the passage of subsequent impulses is lowered, and the biochemical change which underlies this lowered threshold is probably permanent. It is likely that this phenomenon underlies the automatization of motor skills which are performed frequently, including the sequences of gestures which occur again and again in speech production. Hardcastle points out that "much of speech consists of stereotyped, almost automatic utterances which can be primed and triggered off as a whole."(1976, p9).
It seems likely that this automatizatiion of control of speech production may have an important bearing on understanding certain patterns of phonological acquistion. In particular, the failure of some children to change their pronunciation patterns in favour of more adult-like forms may to some extent be explained by the high

degree to which their pronunciations are automatized and hence are resistent to change.

The afferent fibres of the cranial nerves which contribute to speech motor control, originate in sensory receptors of the skin, mucosa, muscles, tendons and joints of the articulatory apparatus. The mechanoreceptors of the skin and mucosa supply tactile information, while those in the muscles, joints, tendons and the periodental membranes supply proprioceptive information.
The specialised mechanoreceptor of the organ of corti in the inner ear provide auditory feedback about the end result of speech production.

Tactile receptors of the oral mucosa and tongue include 'free' receptor endings and more defined, compact and complex receptor endings such as Kraus end-bulbs and Meissner corpuscles. The former may be concerned with relaying a "general sensation of touch" while the more compact and organised receptors provide more acute, discriminated information and are extrememly sensitive to degrees of pressure and may, therefore, play an important part in sensori-motor co-ordination of speech, (Hardcastle, 1976, p.16). It is known that tactile receptor endings are particularly plentiful in the front areas of the mouth and tongue, where the majority of precise articulatory movements occur, and their frequency decreases towards the back of the oral region. Tactile receptor endings provide information after the event, concerning localization of contact between articulators, for example in alveolar/lingual contact on production of an alveolar plosive consonant. Experiments involving the use of anaesthetics to deprive a speaker of information from these tactile receptor organs have shown that significant alterations in articulatory accuracy result, particularly in the precision of articulatory placement for 'complex' articulations such as aveolar and palato-alveolar fricatives (Gammon, Smith, Daniloff & Kim, 1971, cited by Edwards M., 1984, p.28)
A spatial projection of tactile information from these receptors is relayed via the cranial nerves to the somesthetic cortex, and information is also sent to the cerebellum where it is integrated with other sensory information contributing to cerebellar control over co-ordination and timing of speech gestures. Tactile information is conveyed via relatively small afferent fibres and must

cross many synapses on its way to the cortex, hence tactile feedback is relatively slow acting compared with proprioceptive feedback, which is extremely fast acting and important for all articulatory movements.

Proprioceptors which play a part in speech motor control include joint receptors in the temporomandibular joint which respond to stretch on the joint capsule and hence provide information about mandible action during speech; tendon receptors which respond to stretch and are able to inhibit muscle action to prevent damage; receptors situated in the periodental membranes which are sensitive to pressure and may relay information concerning tongue contact during articulation, and the muscle spindles located in all the muscles involved in speech. Muscle spindles, in particular, play a crucial role in the myodynamic control of speech production. (A full description of their complex structure and function can be found in Hardcastle, 1976). The muscle fibres within muscle spindles (intrafusal fibres) are supplied by both afferent and efferent nerve fibres. Muscle spindles are found in greatest numbers in those areas of the speech musculature where the most precise and delicate adjustments of action are required, such as the tongue tip.

The discharge from the spindle afferent fibres provides extremely fast-acting feedback about the degree of stretch in a muscle and, perhaps more importantly for motor control of speech, information about the rate of change of muscle lengthening. This feedback may provide the CNS with 'predictive' information which allows on-going adjustments to be made to the efferent commands sent to both extrafusal muscle fibres and to the muscle spindles. The sensory feedback from a muscle spindle is capable of influencing not only the efferent commands to the muscle in which the spindle is situated but also the efferent commands to the synergistic and antagonistic muscles involved in a particular gesture or series of gestures. Thus, the efferent supply to muscle spindles combined with their afferent connections and with the main alpha motoneurone supply to muscles, provides the basis for servomechanisms for the precise regulation of movement. That is to say, during speech, the mechanism ensures that the right amount of gamma and alpha neurone activity is sent to the periphery to achieve the degree and velocity of articulator movement required for a particular articulatory target under a variety of conditions and from a variety of starting positions. For example, the firing of dynamic gamma efferents to muscle spindles may be able to accelerate the contraction of a muscle and allow it to move towards a target configuration more rapidly when phonetic context demands. Furthermore, it is possible that the fine, reflex-based regulation provided by the efferent fibres to muscle spindles allows the final length of a muscle to be predetermined irrespective of length at the outset of a movement. These abilities of the spindle servo-mechanism may explain how particular gestural spatial targets can be achieved in a variety of circumstances without the need to posit a huge number of commands at higher neural levels to meet every eventuality (Hardcastle, 1976). That is, the spindle servo-mechanism constitutes a significant part of the physiological basis for 'speech motor equivalence' discussed in section 1.5.1. above.

Auditory feedback also plays a part in the development and on-going control of speech movements. Auditory information about the outcome of speech movements is, by definition, feedback after the event and, since it involves external transmission through air and bone as well as internal transmission through the central and peripheral nervous system, it is slow acting compared with either tactile or proprioceptive feedback. Hardcastle suggests that auditory feedback may be particularly important for speech sound targets which result in relatively little tactile information such as open back vowels.

1.5.2.3. Neurophysiological maturation in relation to the development of speech motor control.

In the first section of this chapter a number of types of investigation were cited which have indicated that speech motor control abilities develop gradually throughout childhood towards adult levels of performance. Aspects of speech motor skill which are known to be less developed in young children compared with adults include speed of execution; control of consistency of temporal and other phonetic features; ability to perform complex integrated combinations of articulatory gestures and ability to adapt to and compensate for external constraints on articulatory performance. The complexity and degree of interconnection among motor and sensory components in both the central and peripheral nervous systems involved in speech production has been emphasised above. The full integration of these various components, upon which mature speech motor control in adult speakers depends, must develop gradually in infancy and childhood as a results of both physical maturation and learning. The importance of sensori-motor exploration and learning during speech development is stressed by Abbs & Kennedy (1982, p 102). During childhood the speed and efficiency of speech motor performance increases and becomes more automatised as a result of increasing speed and efficiency of neural transmission, particularly at synaptic junctions as described above; and motor commands come increasingly under the influence and control of afferent (sensory) systems at all levels leading to increased adaptability and flexibility and to finer, more precisely targeted movements and to more consistent control of articulatory gestures in a variety of circumstances.

Edwards M., 1984 suggests that in developing speech, external feedback channels play a crucial role in establishing 'cerebral templates' of articulatory gestures. That is, in the course of speech acquisition, it is likely that a child integrates auditory information derived from the speech forms he hears, with auditory, tactile and proprioceptive feedback from his own speech production to build up internal schemata of neural instructions which eventually enable him, in a variety of circumstances, to perform the articulatory gestures required to achieve the auditory / spatial configurations which specify all the speech sounds of the adult language. Thus the neurophysiological resources available to a child increase gradually from infancy to adulthood, opening ever increasing possibilities to the child in terms of speed, accuracy and complexity of speech production. These aspects of development must interact with cognitive and linguistic aspects of development to bring about the child's eventual mastery of the full range of sound contrasts and combination of the adult target language.

1.6. PHONOLOGICAL DEVELOPMENT IN THE CONTEXT OF PHONETIC DEVELOPMENT.

This final section of the chapter draws together the various strands discussed above and focuses the argument, which provides the rationale for the current investigation, that phonological development (and therefore phonological disability) cannot be considered in isolation from phonetic (neuromotor) aspects of development.

Jakobson (1968) described the pre-speech babbling stage of vocalization as a phase in which all sounds of which the human vocal tract is capable are randomly produced and he viewed the beginnings of 'true' speech development as a totally separate process in which relatively few sounds are produced, and in which these sounds now have linguistic significance and are determined by the nature of the language to which the child is exposed. The implications of this view are that children's phonetic development is complete by the end of the babbling stage and that after this phase the child has only to learn the phonological rules and contrasts of the language. Jakobson's claims for the separateness of babbling and the onset of speech tended to divert interest from phonetic aspects of speech development (MacNeilage, 1980).

However Jakobson's view has been much questioned, (see, for example, Ferguson & Garnica,1973; Kiparsky & Menn,1977), and it is now widely accepted that babbling and early speech development overlap to a considerable extent. Oller (1980); Cruttenden (1970) and Menyuk (1971), among others have shown that the consonants which predominate in the later stages of babble tend to be those which are also found in the child's first meaningful utterances. On the other hand, Davis & MacNeilage (1990), in a quantitative study of developing vowel systems, found that there was not always a close connection between the vowel-like sounds of late babble and the early stages of vowel system acquisition.

A child's vocalizations are considered to have the status of words (or proto-words) when a particular sound sequence is consistently associated with a particular meaning, which may or may not bear a close relationship to the meaning attached to an adult word which the child's utterance resembles. At this stage it is thought that the

child's utterances are organised at a holistic, word level; that is, the child does not identify or attempt to reproduce the individual phones of the language but treats words as 'phonetic wholes'. This early stage, roughly between ages 1.0 -1.6 years is sometimes referred to as the 'first fifty word stage' (Ingram 1976).
After this early stage the child's utterances begin to show evidence of organisation at levels below that of whole words and it then becomes possible to identify consistent relationships between the child's pronunciation patterns and adult phonological forms; that is, a certain limited range of syllable structures and sound contrasts can be identified in the child's output. At this stage,

> the child's pronunciation patterns exhibit regularities which yield to a systematic description within a phonological framework. (Hewlett, 1990, p 19).

As described above (section 1.2.2.), certain patterns or types of realisation rules re-occur again and again when developing speech is analysed, and these commonly occuring rule-types have come to be recognised and given 'short-hand' labels such as 'stopping', 'velar fronting', 'cluster deletion', 'voicing' etc.. Following Stampe (1969) these commonly occurring rule types have become known as simplifying phonological processes.
Far from accepting Jakobson's position that the child has learned all there is to learn about speech sound production by the end of the babbling period, an underlying assumption in Stampe's Theory of Natural Phonology is that the simplifying phonological processes observable in developing speech are the result of mental operations which the child performs to enable him to achieve spoken language output within the limitations of his immature speech production abilities. Stampe believes that these processes, which simplify articulatory production and therefore reduce the articulatory demands of utterances, are 'natural' or 'innate' and occur universally in developing speech. In this view phonological acquisition involves the gradual suppression and eventual elimination of these innate processes until the child's speech is fully adult-like in phonological form.

In relation to this view of phonological development, Menn (1983) argues that phonological acquisition should be regarded not only as a cognitive process of gradual suppression of innate mental operations but as an process of active phonetic learning in which 'suppression' of simplifying processes comes about as the result of the child learning to program and execute new and more complex articulatory manoevres. In her view, simplifying phonological processes should be regarded as representing "One type of reaction to the complexities of adult phonotactics" (Menn 1983, p 4), that is, as the observable manifestation of one of a number of strategies that children may draw upon in their attempts to reproduce adult words within their limited articulatory capabilities. Menn also discusses other strategies which are available to the developing child such as lexical avoidance and exploitation of favourite sounds.

Stampe's view of the 'innateness' of phonological processes is an issue of continuing controversy. Menn, for example, suggests that the commonly occurring processes are 'natural' only in the sense that the physiology of the speech production mechanism dictates that some 'errors' are more likely than others. The fact that there seems to be an identifiable order in which simplifying phonological processes disappear (are suppressed) and in which classes of speech sounds appear in the course of normal development suggests some sort of ease of articulation hierarchy among speech sounds and speech sound combinations,

> We certainly have reason to say that 'stopping' and 'voicing' are natural in initial position; that is, we have reason to believe that there is a high, physiologically governed, probability that the child making a first attempt at an initial fricative will produce an initial stop and that the child first attempting an initial voiceless stop will produce a voiced stop instead. This, I think, is the only coherent interpretation of the notion 'natural process'.
> (Menn, 1983, p 23).

However, it may be that the ease/difficulty dimension for the range of speech sounds for an individual child is not entirely a matter of physiology, but that the child's state of knowledge at the time and the chance factor of which of a class of sounds he happens upon first also play a part in the pronunciation patterns he adopts.

As discussed above, the balance of evidence from perceptual studies is that children's ability to perceive phonological contrasts develops well in advance of their production abilities, which would imply that, in some sense at least, children acquire knowledge of the phonological rules of their language well before they are capable of giving evidence of such knowledge in their spoken language output. In section 1.4., above, evidence was cited which suggests that children may have knowledge of phonological contrasts which they appear to neutralise in their speech, for example; Maxwell & Weismer (1982); Macken & Barton (1980); Catts & Kamhi (1984); Weismer, Dinnsen & Elbert (1981) and Gibbon (1990).

The relationship between a child's perceptions of adult forms and his stored lexical representations is the subject of much debate. If a developing child perceives an adult form accurately does he also store that lexical item in fully adult-like form, or does he store it in simplified form, or does the child in fact have two representations of a lexical item, the adult form which is used in decoding an utterance and a simplified 'output' form based on his pronunciation of the word ? (Stoel-Gammon & Dunn,1985). The last of these possibilities, a two-lexicon theory has much potential in explaining a situation in which children perceive phonological contrasts but neutralise the same contrasts in their speech output. Two-lexicon theory of developing speech, in which simplifying phonological processes are regarded as the rules which 'capture' the relationships between input and output forms, is supported by Menn (1983) and by Chiat (1983); and a two-lexicon model of speech production proposed by Hewlett (1990) was described briefly in section 1.5.1. above and is discussed again in the final chapter of the thesis in relation to the results of the current investigation.

Evidence from acoustic studies of durational and other phonetic features in child and adult speech (see section 1.1.1. above and Chapter Two) have shown that children's phonetic abilities continue to mature throughout childhood. In section 1.5. it was argued that gradual maturation and integration of the neurophysiological systems involved in speech production and control underlies this gradual maturation of phonetic abilities.
Kent (1984) stresses that the acquisition of phonology and the acquistion of motor control for speech interact in an inseparable way and he regards the development of speech as the co-emergence of language and a movement system, that is, the development of speech must be understood not only in relation to cognitive and linguistic structures and functions but also in relation to the organisation of

movement sequences and therefore in relation to the anatomical and neurophysiological maturation of the vocal tract and of the central and peripheral nervous systems. Kent suggests that many of the characteristic sound patterns identified at various stages of babbling can be predicted on the basis of anatomical changes in the relative proportions and positions of vocal tract structures, for example, the common occurrence of velar sounds in early babble and their relatively infrequent occurrence in later stages of babble is explained in terms of the high position of the larynx in very early infancy: and to emphasise the inseparability of the phonological and motor aspects of speech development, he discusses the occurrence of reduplicated sound patterns which is a significant stage in the development of babbling behaviour and also in the early stages of speech. He suggests that the production of reduplicated patterns which is often interpreted as a 'phonological process' should be considered not as a "limited phonological process but rather as part of a more general developmental process in which cyclicity is used to motor advantage" (p.891); that is, such rhythmic, reduplicated movement may contribute to "an infant's discovery of optimal timing control or kinesiological efficiency and the development of co-ordination within and among motor systems" (p.892).

The importance of the reduplicated babbling stage is further elaborated in the context of the interaction between motor and linguistic aspects of speech development by MacNeilage & Davis (1990). In their view mature speech production is the ultimate refinement of the primitive, repetitive, cyclic rhythmic open-close alternation of the mandible accompanied by phonation which is observable in some variants of the lip-smack, which is widespread in other primates, the initial babbling of human infants, and in the production of the syllables of adult speech. The increasing variegation of syllable patterns as speech develops is achieved by "placement of independently controlled 'content' elements in syllable 'frames'" (p.55). In this view the production of syllable 'frames' is seen as the unit of rhythmic organisation which serves as the structure controlling the serial position of individual segments, and the production of rhythmic syllable-like vocalisations is regarded as a precursor to the development of speech both in an evolutionary sense and in the development of the human infant.

Neurophysiological studies have suggested that vocalisation in lower primates is under the control of the primary motor cortex and of the Supplementary Motor Area (SMA), see section 1.5.2. above. Electrical stimulation studies of the SMA in human subjects, for example, Penfield & Welch (1951), and evidence from patients with irritative lesions of the SMA (Jonas, 1981, reported in MacNeilage & Davis, 1990) have reported that rhythmic syllable-like vocalisations have been evoked. In evolutionary terms the capacity required for the production of 'content' elements in speech is dependent on the development of the lateral frontal cortex, particularly Broca's area (MacNeilage & Davis 1990, p 56). The human infant is seen as recapitulating these evolutionary steps as he achieves neurophysiological maturity, that is, developing 'frames' , which involve a relatively gross level of control, at the outset of babbling in association with maturation of the SMA: and, much later, following a developmental progression , achieving independent segmental content in association with maturation of other cortical areas involved in speech production.

At the reduplicative babbling stage the differences in sound quality heard from one occasion to the next are explained as the result of differences in the amplitude of mandibular oscillation and of different resting positions of other articulators or of articulatory 'presettings' which are maintained through the entire utterance. That is, a reduplicated utterance such as [dada] which gives the impression that two gestures of the tongue apex have occurred may result simply from the fact that neither the tongue position nor the amplitude of the mandibular oscillation change during the utterance.

At the variegated babbling stage, MacNeilage & Davis suggest the 'vertical' variations of vocant height and degree of constriction of closants are due to these same 'frame' variables, while 'horizontal' (front-back) axis variations are due to newly developing 'content' factors. At the early speech stage this frame / content model suggests a provocative reassessment of the common descriptive terms applied to infant pronunciations of adult words. That is, young children are regarded as, "simply approximating adult forms with the best fit to their babbling-derived motor repertoires", rather than applying 'rules' to derive their own forms from adult forms. For example, a realisation of the word 'duck' as [gʌk] would be regarded as the result of a preference for reduplication rather than given the traditional label of 'assimilation' between consonant segments; realisations such as [tɪk] for the word 'stick' would be regarded as preference for CV structure rather than given the traditional label of 'cluster simplification'; and a form such as [nænə] for the word 'banana' which would traditionally be labelled 'weak syllable deletion' would be seen as a preference for 'rhythmic uniformity'. MacNeilage & Davis acknowledge that it is more difficult to account for the many varied pronunciation patterns found in the later stages of phonological acquisition simply in terms of a child chosing approximations to adult words from the babbling repertoire, however they are able to suggest extended frame/content explanations for selected examples from the literature; for example they suggest that children who seem to approximate a number of adult words by employing a particular 'multisyllabic whole-word template' (Macken, 1978) are in fact employing a "special purpose non-reduplicative frame" (p.64).

This 'frame / content' model of speech acquistion would seem to suggest some powerful explanations for many of the characteristic patterns found in early vocalisations and in early speech and perhaps also for the characteristics of speech of children with delayed speech acquisition. It is consistent with an 'Action Theory' view of speech production in which the production of vowel segments and consonant segments are seen as being under the control of qualitatively different sets of co-ordinative structures, and it suggests ways in which direct links might be established between neurophysiological maturation and the observed characteristics of babble and early speech in infancy. Consideration of such a model illustrates forcibly that while many factors are involved in the development of speech, that is, cognitive / linguistic, perceptual, motor, environmental and learning-style factors as discussed in section 1.3.2. above, motor development factors must be explicitly taken into account in any attempt to understand normal and delayed speech sound acquisition. MacNielage & Davis themselves stress that while motor factors cannot be regarded as the only relevant factors in speech production development, they are likely to "exert crucial influences throughout the entire span of the speech acquisition process".

In conclusion, consideration of evidence from a wide variety of experimental investigations, descriptions of delayed and developing speech, current issues in relation to the motor implementation of speech and knowledge of the neurophysiological basis of speech production leads to the view that children's phonological development is intimately linked to the development of their phonetic (speech motor) abilities. It seems probable that although children's pronunciation patterns are governed by organising principles at a central, phonological level, as evidenced by the largely rule-governed, predictable nature of their speech output, this organisation may be motivated by more peripheral constraints operating at phonetic level; that is, the sets of phonological rules which can be identified in developing speech may represent a central (phonological) response to peripheral (phonetic) limitations. Furthermore, if it is accepted, as is the case in generative theories of phonological development, that simplifying phonological processes in normal development serve to reduce demand on children's immature speech production capabilities, it seems logical to suggest that the need to reduce demand in the face of continuing speech production (phonetic level) constraints may underlie the more persistent and widespread occurrence of these processes in the speech of children who exhibit disability at the phonological level, and this argument provides the rationale for the investigation reported below. The experimental method employed in the current investigation is drawn from acoustic studies of adult and child speech which were described briefly in section 1.1.1. above. Those studies which have had a direct bearing on the design of the current investigation are reviewed in more detail in the following chapter.

CHAPTER TWO

REVIEW OF STUDIES
WHICH ARE IMMEDIATE PRECURSORS TO THE INVESTIGATION

This review concentrates on studies, selected from those discussed in Chapter One, which investigate aspects of the development of speech motor control and which have the closest relevance to the investigation reported in this thesis. The first section describes studies which have investigated speech motor control in adults and children, utilising acoustic analysis techniques to measure phrase and segment durations and variability of durations and other phonetic features in multiple token speech samples. The second section focuses on investigations of the relationships among speaking rate, age, temporal variability and effects of length of utterance on speaking rate. In the final section of the chapter methodological issues arising from these investigations are critically discussed, with particular reference both to the interpretation and validity of the findings and to factors which have contributed to the design of the current experiment reported in Chapters Three and Four.

2.1. DEVELOPMENTAL CHANGE IN PHRASE AND SEGMENT DURATION AND PHONETIC VARIABILITY.

Studies span the period from 1969 to the mid 1980's and are reviewed in chronological order.
Eguchi and Hirsch's (1969) study was one of the earliest to examine change in a variety of phonetic characterisitcs of speech with age. Their eighty-four subjects included adults and children, aged between 3 and 13 years, divided into age groups with five or six subjects in each group. The speech data consisted of five repetitions of each of two sentences. Adults and children over 7 years read the sentences and younger children were required to repeat the sentences after an adult speaker.

Acoustic measurements using spectrographic analysis focused on changes in absolute values and variability of fundamental frequency and vowel formant frequencies with age as well as on changes in the duration and variability of voice onset times (VOT) in syllable initial plosive consonants. For all variability measures both standard deviations and relative variability (ratio of standard deviation to a subject's own mean) are reported, but the authors favour the use of the relative variance measure. This issue is discussed in section 2.3.5.2. below .

As was predicted from knowledge of developmental physical changes in the dimensions of the vocal tract there was a decline in absolute frequency measurements with age, but the findings relating to intra-subject variability of frequency and duration measures were of greater interest. Eguchi & Hirsch reported that for fundamental frequency and for first and second formant frequencies of vowels there were systematic decreases in individual variance with age (up to age 10 or 11 years for fundamental frequency and up to age 11 - 13 years for vowel formant frequencies).
No systematic age-related change in mean VOT intervals were found, but there was systematic decrease in individual variabilty of VOTs from age 3 up to approximately age 8. After these ages variability matched adult values.
The authors consider that an individual's variability on these measures can be regarded as the inverse of the individual's precision in the execution of these aspects of speech production and that the result "of greatest interest" from their study was the "change in precision or reproducibility of certain aspects of speech sounds" with age. They do not, however, make an uncritical assumption that this apparent developmental increase in precision of execution of speech is necessarily a consequence of increased motor control for speech. They discuss the possibility that the greater variability found in the speech of young children might reflect a corresponding inaccuracy in auditory discrimination for these same aspects of speech. However, at least in relation to the segmental durations measured in the study, there is evidence to suggest that the variability found is more likely to relate to motor control processes than to perceptual abilities, since several investigators have found that adult-like discrimination ability for voice onset time differences seems to be present in children as young as 3 years. For example Winterkorn (1967) tested 3 year old subjects' discrimination of voice onset time distinctions using synthesised CV syllables. The

children were found to accept only stimuli with voice onset times of 20 ms or less as representing the syllable /də/ and only those with VOTs of 45 ms or more as representing the syllable /tə/. Such evidence of the early attainment of adult-like perceptual capacity for temporal features of speech tends to support the validity of regarding measures of variability in multiple tokens as an index of the status of speech motor control, and of accepting the findings of Eguchi & Hirsch's study as evidence of gradual development of speech motor control ability throughout childhood.

In a series of papers, DiSimoni (1974 a, b & c) reports the results of investigations of segment duration in repetitions of nonsense syllables by 3, 6 and 9 year old children (thirty subjects in all). CVC syllables were elicited to study the effects of consonant environment on vowel duration; VCV syllables to study the effects of vowel environment on consonant duration, and, in the third part of the investigation, VCV syllables within carrier phrases of increasing length were elicited in order to study the effects of utterance length on closure duration in plosive consonants. In all cases three tokens of each experimental syllable were analysed from each subject. Temporal measurements were made from oscillographic traces.

The central concern of DiSimoni's investigation was to demonstrate developmental trends in context-conditioned variability of segment durations. The results indicated that the effects of vowel environment on consonant duration increase over the age range studied, but have still not reached adult values by the age of 9 years; effects of consonant environment on vowel duration also increase over the age range, with the most rapid change occuring between the ages of 6 and 9 years. The shortening effect on plosive consonant closure duration of increasing utterance length is also greatest in the oldest children. Although many of DiSimoni's results fall short of statistical significance, they demonstrate fairly convincingly that there is a developmental trend over the age range studied towards greater context-bound variability of speech segment durations. Given that all these contextually conditioned effects necessarily involve motor planning over units of a syllable or longer, DiSimoni argues that the observed developmental trends indicate increasing skill in forward scanning / planning ability in the motor execution of speech patterns with age.

DiSimoni also reports results for age-related change in absolute durations and variability of durations of speech segments in the same phonetic environment. He found a developmental trend towards less context-free variation in segment durations which is interpreted as an indicator of increasing speech motor control in that older children appear to be better able to reproduce accurately a particular spatio-acoustic target. However, DiSimoni's findings on context-free variability must be viewed with caution since the reported trends do not always achieve statistical significance. Furthermore, the statistical analysis deals only with pooled group data; that is, DiSimoni's conclusions on context-free variability are drawn on the basis of the group means and group standard deviations for three tokens of an utterance spoken by each of the ten members of each subject group. In two of the investigations the data is further pooled across types as well as tokens: for example, in the study involving the effects of consonant environment on vowel duration, the conclusion that, "Speaker variability declines with age" is drawn on the basis of results pooled across all subjects within a group and across two different phonetic contexts. Thus interpretation of these results is complex since "Speaker variability" is in fact being assessed using measures of central tendancy and variance which include intra-subject and within-group inter-subject variance as well as variance between types rather than between repeated tokens. Nevertheless, in spite of these caveats, DiSimoni's study does seem to lend broad support to Eguchi and Hirsch's findings in that the results suggest a gradual developmental trend towards increasingly precise, adult-like and reliable execution of the timing features of speech segments which can be interpreted as a reflection of gradual maturation towards adult-like motor control for speech.

Tingley & Allen (1975) report a study which aimed to determine the extent to which speech motor control improves with age and to investigate the importance of peripheral feedback in the maintainance of timing control. Tingley & Allen's experimental design and discussion of results centre on a complex statistical model of speech motor control which attempts to distinguish among factors which may contribute to the observed overall variability of the timing characteristics of an individual's speech output. The statistical model provides for variations which result from small errors in a proposed "neural clocking mechanism" ; variations resulting from changes in overall speaking rate between repetitions of the same utterance; variations arising from differences in articulation between repetitions and variations which are the result of measurement error.

Twenty subjects were included in this study, five subjects in each of the age groups 5, 7, 9 and 11 years. The speech data consisted of thirty spoken repetitions of the first line of a nursery song. Acoustic analysis used oscillographic traces from which the time intervals between nine selected phonetic 'events' were measured. Individual subjects' variability for each of the time intervals was assessed using a measure of relative variance (that is, the ratio of the standard deviation to the subject's own mean).
Tingley and Allen found a clear relationship between individual relative variance and age, in which the youngest children were the most variable. Their results therefore support the findings from previous studies and the authors conclude that the results "strongly suggest that the speech timing control mechanism has a developmental component" (Tingley & Allen,1975, p190).

Smith (1978) investigated child and adult performance in relation to temporal distinctions which serve as primary perceptual cues in English (voice onset times of plosive consonants and contextually conditioned vowel durations) and in relation to timing features which do **not** serve as primary perceptual cues but which are consistent characteristics of adult speech (stop consonant durations at different places of articulation and segment durations in different syllable positions).

He measured segment and syllable durations in ten tokens of nine nonsense syllables spoken by three groups of subjects (2;6 - 3 year olds; 4 - 4;6 year olds, and adults).
Both groups of child subjects revealed syllable and segment durations which were consistently longer than those of adults, but although absolute durations were greater for the children, Smith found that both groups of children behaved very much like the adults with respect to the proportional differences in segment durations - that is, with respect to language specific relationships in temporal differences.
Smith concludes from his data that the longer durations found in young children's speech reflect their inability to exert adult-like

control over their speech production and hence their less refined neuro-motor capabilites. However, he also concludes that in spite of such limitations children as young as three seem to "recognise important temporal parameters of the language they are learning and incorporate them into their phonological systems".
In the introduction to his paper Smith states that temporal variability is not a primary concern of his study. He does, however, report group standard deviations for his measures of syllable duration; that is, inter-subject variability for each subject group, but does not report intra-subject variability. The analysis of within-group inter-subject variability for syllable durations indicates that the youngest children were more variable than either of the other subject groups but that the four-year-olds were very similar to the adults in this respect.

Smith's omission of discussion of intra-subject variability is surprising, as are the rather equivocal results on inter-subject variability, in view of the fact that greater durational variability in young children's speech had been such an integral part of previous developmental studies of speech timing.
It is possible that the failure of Smith's study to support other findings on developmental trends in variability of speech timing was a consequence of his methodolgy: Smith collected an unspecified number of tokens of each nonsense word from his subjects and then selected, "those productions which were judged to be the best ten" for analysis. Selection was based on how "normal" and "accurate" the token sounded and if "either the experimenter or the assistant felt that a somewhat aberrant token had been produced" that token was excluded from the data. It seems likely that this selection procedure masked the true extent of both inter-subject and intra-subject variation in the child subjects.
In a recent paper (Smith 1992), selected results from this investigation, together with selected results from Smith, Sugarman & Long (1983) are re-analysed with a greater focus on intra-subject variability and on the relationship between temporal variability and absolute durations, see section 2.2.4. below.

Two related investigations by Hawkins (1973 & 1979) yield both cross-sectional and longitudinal data relevant to the development of temporal control of consonant articulation between the ages of four

and eight years. The focus of the studies is the duration of clustered and unclustered pre-vocalic consonants in English monosyllables spoken by seven children aged between four and seven years and by six of those children and one other child approximately 14 months later. Five adult subjects were also included for comparison.
Adult subjects were required to read lists of the experimental words while the child subjects repeated the words after the investigator. Between twenty and thirty tokens of each experimental word were examined from each subject in each phase of the investigation and the required segment durations were measured oscillographically.
Group results are reported for the three subject groups. That is, for adults, for the children in Year One of the study and for children in Year Two of the study. These group results showed that the younger children tended to display **more** context-free durational variability but less durational differences between segments in different phonetic contexts (that is, clustered and unclustered contexts).

Hawkins relates these findings to phenomena which are well attested in other areas of motor skill learning. That is, that younger children are less accurate in their execution of fine motor tasks,and therefore display greater variability in repetitions of the same target; and are less able to differentiate between contexts and therefore display less systematic temporal variation in different phonetic contexts.

A study by Kent & Forner (1980) is one of the most widely quoted investigations of speech motor control development. Spectrographic analysis was used to measure phrase and segment durations in sentence repetitions by adults and children aged 4, 6, and 12 years. There were ten subjects in each age-group and four tokens of each of three sentences were collected from each subject. The order of presentation was randomised and all subjects were required to repeat the stimuli after the investigator.

Results for phrase duration measures demonstrated that the group mean value declined with age and the group standard deviation (within-group variability) was larger for 4 year-olds than for the other age groups. Analysis of intra-subject variability for the phrase duration measures indicated a rather weak developmental trend, with the younger subjects being somewhat more variable than the older subjects. However, the performance of the subjects within a group was not uniform, that is, some of the 4 year-olds had individual standard deviations for phrase duration within the adult range, whereas others had standard deviations well outside the the range of values found for adults. Hence "some young children are apparently capable of much more reliable control over speech production than others".

Results for segment durations also showed that younger subjects had longer group mean durations, greater heterogeneity within the group and poorer individual consistency than older children and adults.

The authors of this study are careful to point out that because they, "examined only a small number of sentences and a small set of measurements, it is not warranted to draw sweeping generalisations about segment durations and variability from the data ". In particular, the results pertaining to intra-subject variability must be interpreted with caution since only four tokens of each of the three experimental sentences were available.

In Chapter One, section 1.4., the few investigations which have examined temporal acoustic features in data from normal and language disordered children were discussed, (Weismer & Elbert,1982; Amorosa,1982 and Catts & Jensen,1983). Of these, Catts & Jensen's study is the most relevant to the investigation reported in this thesis; since it is concerned with young children (3;10 - 5;7 years) who are regarded as having specific phonological / articulatory problems. The experiment involved nine normal and nine disordered subjects classified as having moderate to severe articulation disorders assessed on the Arizona Articulation Proficiency Scale (Fundala, 1974). The speech data consisted of multiple tokens of CVC words embedded in carrier sentences. The experimental words were chosen to sample contrasting voiced and voiceless stops in similar phonetic environments, for example the words 'dear' and 'tear' were used. Measurements of voice onset time, vowel duration, consonant closure duration and percentage voicing during consonant closure were made from spectrograms.

Catts & Jensen's results showed that both phonologically disordered and control subjects exhibited differential vowel durations and consonant closure durations in voiced and voiceless final stop contexts. They found no significant difference in intrasubject variability between the two groups on measures of vowel duration or consonant closure duration.

The disordered subjects had significantly longer closure durations than normals and also less voicing during closure for word final stops. On the VOT measures in word initial stops it was found that experimental and control subjects had similar distributions for voiced targets but significantly different distributions for voiceless targets. That is, whereas the normal group had a bell-shaped distribution curve for VOT in voiceless initial stops with a mode at +70 ms, the disordered group exhibited a bimodal distribution which indicated that there were two subgroups within the disordered subjects. The first subgroup realised voiceless stops with short-lag VOT, and were labelled as 'non-contrastive', the second subgroup distinguished between voiced and voiceless targets on the basis of VOT but their mean VOT for voiceless targets was found to be significantly longer compared with the control subjects (112 ms compared with 75 ms). The authors suggest that these 'contrastive' phonologically disordered subjects are at an intermediate stage of development of the voicing contrast in which they are able to achieve differential VOT but lack sufficient motor control to attain an adult-like distribution of values. They also suggest that the longer mean closure durations found among the disordered subjects can be interpreted as reflecting less mature neuromuscular control for speech. Catts & Jensen do not give much emphasis in their discussion of results to the lack of significant difference between their normal and disordered subjects on the measures of intra-subject context-free temporal variability in spite of the fact that this is regarded as an important indicant of level of maturity of speech motor control and this aspect of the results therefore weakens their assertion that the disordered subjects had poorer speech motor control than the normal subjects.

2.2. SPEAKING RATE IN RELATION TO AGE, TEMPORAL VARIABILITY AND LENGTH OF UTTERANCE.

A number of developmental studies of speaking rate were reported in Chapter One, section 1.2.: Fletcher (1972) investigated DDK rates in children between the ages of 6 and 13 years; Canning & Rose (1974) in a similar study with British children examined DDK rates in children aged 4 - 14 years; Amster (1985) investigated speech rate in connected speech data from preschool children; Henry (1990) measured DDK rates in normal children between the ages of 3;4 and 5;8 years and in a group of speech and language disordered children and Walker et al (1992) measured speaking rates (in phones and in syllables per second) in spontaneous speech and in imitated connected speech data.

All these studies, regardless of type of data examined, have indicated that age is a highly significant factor in determining rate of speech performance and have regarded this relationship as evidence of a developmental increase in speech motor control abilities.

This section expands upon the discussion of developmental increase in rate of articulatory/speech performance to include investigations of the inter-relationships between developmental change in speech rate and each of the following variables: speaking context; type of rate measure; utterance length and temporal variability. Some of the investigations discussed below have adopted a straightforward correlational approach (for example, Kowal, O'Connel & Sabin, 1975 and Slis, Haselager & Rietveld, 1988); while others have employed experimental manipulation of speaking rate to evaluate these relationships (for example, Smith, Sugarman & Long, 1983 and Chermak & Schneiderman, 1986).

2.2.1. Speaking context and type of data.

In general, speech rates in spontaneous speech are found to be slower than in DDK tasks. For example Fletcher (1972) found that rate in a stop-vowel DDK task increased from four syllables/second at 6 years to six syllables/second at age 13 years; whereas in spontaneous speech data Kowal, O'Connel & Sabin (1975) found rates of approximately two syllables/second at age 6 years rising to approximately four syllables/second at 14 years.

Slis, Haselager & Rietveld investigated the relationship beween speech rate (measured in syllables/second) and age in both spontaneous speech and in a DDK task. Subjects were forty children, ten in each of the age groups 5, 7, 9 and 11 years. Results confirmed that rate in the DDK task was in general significantly faster than in spontaneous speech and the authors suggest that this is explained by the repetition task requiring less total processing capacity than spontaneous, communicative utterances, and therefore, in DDK tasks more processing capacity is available for achieving control over rapid articulator movement. However Walker, Archibald, Cherniak & Fish (1992) in the only study to compare articulation rates in spontaneous and imitated connected speech data found significantly faster rates in spontaneous speech compared with imitated sentences. They suggest that this unexpected finding might be explained by the attention which their young child subjects (aged 3 and 5 years) had to give to the task of duplicating exactly a sentence spoken by the investigator.

2.2.2. Type of rate measure.

Walker et al (1992) examine the correlation between speech rate measures in syllables/second and in phones/second in their spontaneous and imitated sentence data. Highly significant correlations were found between the two measures in all cases.

2.2.3. Utterance length.

The investigations by Kowal et al (1975) and Slis et al (1988) both indicate that age related increase in spontaneous speech rate cannot be interpreted as due solely to improved motor speech production skill since their data also indicated that utterance length, defined as the number of syllables between pauses, also increased with age, and it is widely accepted that mean length of utterance increases with age.

Amster, in her study of preschool children found a positive relationship between length of utterance and speech rate for spontaneous speech data when all age groups (from 2;6 to 5;5 years) were considered together. However, when age groups were examined separately there were only positive correlations between rate and

utterance length at ages 2;6 - 2;11 and 3;6 - 3;11 years (boys only). This result suggests that both age and utterance length affect speech rate, but that the relationship with age is the stronger.
Walker et al (1992) found a positive correlation between speech rate and utterance length in spontaneous speech but not in imitated sentences, but only for their 3 year old subjects (and not for 5 year olds).

Slis et al performed an analysis of variance on their data to determine whether age and utterance length can be regarded as independent factors in their influence on speaking rate. The findings indicated that both age and utterance length are independently correlated with speech rate, and the authors conclude that, in spite of the influence of utterance length, increasing speech rate with age can be regarded as reflecting increasing motor speech skill.

2.2.4. Temporal variability.

In the first section of this chapter several investigations were discussed which have indicated that temporal variability of speech declines with age throughout childhood: this increase in temporal consistency / precision is regarded as reflecting and providing a measure of speech neuromotor maturity. It is important to be aware however that temporal variability may depend to some extent at least on absolute durational characteristics (segment durations / speech rate), which are also known to be age related; and that therefore, decline in temporal variability with age may be an artifact, (Klatt, 1974 and Kent & Forner, 1980).

Smith, Sugarman and Long (1983) report an investigation which involves experimental manipulation of speaking rate with adult and child subjects in order to evaluate two hypotheses concerning the relationships among absolute duration, durational variability and subject age. The first of these hypotheses states that observed durational variability is a function of age, and hence, presumably, of neuromotor maturation and is independent of mean duration: the 'neuromotor maturational hypothesis'. The second hypothesis is that durational variability depends entirely on absolute (mean) duration and is independent of age: the 'statistical artefact hypothesis'.

There were five subjects in each of four groups; ages 5, 7 and 9 years and adult. The data consisted of ten repetitions of a constant phrase at each of three speaking rates for each subject. Spectrographic measurements were made of phrase duration and two syllable durations.

Both syllable and phrase mean durations declined across the four age groups from the 5 year-olds to the adults for each speaking rate, but the relative differences in mean durations between the three speaking rates was similar in all groups, indicating that the children (with a few exceptions) were able to manipulate their speaking rate at will.

Within-group comparisons of relative variability of phrase duration at each speaking rate showed that variability increased as mean duration increased: that is, speakers tended to be most variable when speaking most slowly. However, an analysis of variance found that both speaking rate and age of subject group had significant effects on group coefficient of variation measures.
Further indication of an age related effect on durational variability came from between-group analysis: comparisons of variability were made for utterances of similar mean phrase duration (arbitrarily defined as within +/- 75 ms) produced by adult and child subjects. The child subjects were shown to be more variable than adults when achieving similar mean phrase durations.

Within-group comparisons of relative variability of syllable durations produced a rather different result. That is, all four age groups of subjects were least variable in their syllable durations when speaking at their normal rates and became more variable when instructed to speak either faster or slower.
Again some between-group comparisons of variability were made for syllables of similar mean duration spoken by adults and children. (Similar duration for syllables was defined as +/- 15 ms) and, as for the phrase duration measures it was found that the children tended to be more variable than the adults when achieving similar mean durations.

The evidence from the results of this investigation refutes both of the above hypotheses in their simplest forms. Neither the neuromotor maturational hypothesis nor the statistical hypothesis exclusively accounts for differences in durational variability between children's and adults' speech. Rather, the results suggest that there is a complex interaction among individual neuromotor status, normal speaking rate and conscious manipulation of speaking rate.

An investigation by Chermak & Scheiderman (1986) also employed experimental manipulation of speaking rate to investigate relationships among rate, durational variability and age.
The subjects were five children aged 7years, five 13-year-olds and five adults. The speech data for each subject consisted of fifteen repetitions of a short sentence at each of two rates; normal and fast. All subjects read the sentences from a list interspersed with 'dummy' sentences which were not used in the analysis. For the fast rate of production, subjects were instructed to read at a rate twice as fast as their normal conversational rate. Spectrographic measurements were made of sentence duration and the durations of four content words.

Results showed that as a group the children spoke more slowly and presented with greater variability than adults for both rates of production. Group relative variability for all word and sentence durations differed significantly as a function of age.
Within each age group, the relative variability (coefficient of variation) and absolute variability (standard deviation) increased as word and sentence duration increased. Correlations between duration and variability were strong for the children and teenagers but not significant for adults.
As in Smith, Sugarman & Long's study, Chermak and Schneiderman make between-group comparisons of durational variability where mean durational measures are comparable. These comparisons showed that the children exhibited significantly more variability than either the teenagers or the adults when producing sentence repetitions with similar mean durational values. This is strong evidence that not all the increased variability observed in child speakers can be accounted for by increased absolute durations.

The results of Chermak and Schneiderman's investigation support the conclusion of Smith, Sugarman and Long (1983) that neither a statistical artifact hypothesis nor a neuromotor maturational hypothesis can account exclusively for observed differences in durational variability of speech in children and adults. Both statistical and maturational factors seem to contribute to children's

greater variability.
It should be noted that both Chermak & Schneiderman and Smith, Sugarman & Long report only group results. That is, relationship between group mean duration and variability is compared between age groups but relationship between individual mean duration and variability is not reported.

Smith's, 1992, re-analysis of selected results from Smith (1978) and from Smith, Sugarman & Long (1983) is concerned primarily with the degree of correspondence between measures of intra-subject temporal variability and durational measures. He concludes that, although both duration and variability generally show decreases with age across groups of children, there seems to be only a moderate correlation between duration and variability in individual children and that durational characteristics tend to reach adult-like levels earlier in speech development than does variability.

Walker et al (1992) also report variability measures from their spontaneous speech and imitated sentence data. They did not find any age-related decrease in variability, which at first sight seems to contradict the findings of the majority of studies described in section 2.1. above. However, Walker's variability measure is based on speech rate in ten different spontaneous utterances and four different imitiated sentences and therefore cannot be compared directly with those studies which measure intra-subject, content-free variability in multiple token speech data. Contrary to the widely accepted view that slow speech is more variable than fast speech, Walker et al report that in their study with 3 and 5 year old children, "faster speaking rates were associated with increased, rather than reduced, variability" (Walker et al, p 11).

Crystal and House (1988) adopted a different approach to evaluating the strength of the relationship between duration and variability of speech segments.
Their subjects were six adult speakers; three fast and three slow talkers assigned to these categories on the basis of the time taken to read a 600-word script. Crystal and House investigated the correlations between mean duration and standard deviation for various categories of speech sounds (for example, all vowels) over the whole 600-word passage.
Their main conclusion is that the data support the 'general rule'

that, slow speakers are more variable in timing control than fast speakers (Kent & Forner 1980). That is, the relationship between standard deviations and means for segment durations in the data can be described by a linear regression line.

On the basis of their results, Crystal and House suggest that standard deviation of duration distributions may be a poor index of a speaker's neuromuscular speech skills, thus calling into question many of the conclusions drawn from developmental studies. However, the method of investigation employed by Crystal and House is very different from any of these developmental studies and addresses a different aspect of temporal variability. Most of the evidence for a developmental increase in speech neuromotor control has come from studies which have examined context-free variability in multiple tokens of a constant utterance. It is change in this context-free variability of phrase and segment durations with age which is seen as an index of increasing skill in speech motor control.
In contrast, Crystal and House's study examines temporal variability over categories of speech sounds within a continuous passage of speech. They are, therefore, considering total variabilty; a mixture of (presumably) some approximately context-free variation, given that it is likely that some segments are repeated in similar phonetic environments in a 600-word passage; context-bound variation, that is, the same phone in a variety of phonetic contexts, as well as inherent durational differences between the speech segments included in a category. While the conclusions from this investigation contribute to the understanding of speech timing in adult speakers, it does not seem that the results can be directly compared with those from developmental studies of context-free variability.

The investigations discussed in sections 2.1. and 2.2. each make a contribution to an understanding of the development of speech motor control. The studies considered together cover the age-range 3 - 12 years (and adults) quite comprehensively, but the wide methodological differences make the comparison and synthesis of results difficult. However, in spite of differences in type of speech data and measurements the general indications which emerge are persuasive. That is; firstly, young children tend to have longer phrase and segment durations, (and therefore slower speech rates) than older children and adults, and that this reduction of duration with age is, at least in part, a consequence of neuromuscular maturation and therefore, "durational measurements may be one way of characterizing a child's developmental progress in attaining adult-like speech motor control", (Kent & Forner, 1980, p 158).

The second developmental pattern which emerges from these studies is an age dependent decline in context-free variability of performance. Variability of timing control is considered to reflect degree of maturation of control over co-ordinated motor activities, and Kent & Forner state that "if variability is taken as an index of maturation of motor control, then it appears that a child's speech production continues to improve in precision until at least 11 - 12 years of age" (p 158).
The investigations also indicate that there is a positive general relationship between duration and variability of duration which can account for some, but not all, of the greater variability found in the speech of young children.

This large body of evidence indicating age dependent trends in segmental durations, speech rate and temporal variability therefore offer a means of comparing speech motor control ability across groups of speakers. There have been very few studies which have attempted to make such comparisons between normally developing children and children with speech and language disorders, (see section 1.4., above), and the only studies which have direct relevance to children with phonological disabilities are those by Catts & Jensen (1983), reported in section 2.1. above and the DDK rate study by Henry (1990) reported in section 1.3.2.. There have been no reported studies of speech rate in connected speech for children with phonological disabilities. In the experiment reported in this thesis measurements of mean phrase and segment durations; temporal variability and speech rate in multiple token connected speech data are used to compare levels of speech motor control in adult, normally developing children and phonologically delayed children.

2.3. METHODOLOGICAL ISSUES

The variety of experimental methods employed in the investigations described above highlight several issues which have a bearing on the interpretation of the findings as well as on the design of the experiments reported in this thesis. Each of these issues is discussed below.

2.3.1. Longitudinal or cross-sectional design.

Of the studies described above only Hawkins,(1973,1979) involves a longitudinal design. Hawkins points out that certain aspects of the development of speech motor control can only be investigated using longitudinal data; that is, phenomena encountered in other areas of motor skill learning such as overgeneralisation of newly acquired rules of performance and the occurrence of phases of rapid change alternating with relatively quiescent phases. However, in Hawkins' study, the age range covered is represented by only one child in each (approximately) six month age interval, and by these same children when 14 months older. Thus the conclusions on developmental trends are drawn from limited longitudinal data from a group which spans a fairly large age range (4;1 years - 7;2 years) and which is therefore likely to have been heterogeneous in all aspects of development. In her summary Hawkins cautions that, "statements linking maturity of developmental stages to age must be taken as very approximate, and relevant to group data only: individual children can vary tremendously in the apparent maturity of their articulatory and timing abilities."
It would be necessary to follow many children over a long period of time to demonstrate conclusively developmental trends in speech motor skill using a longitudinal design: a notoriously difficult form of investigation. It is suggested therefore, while accepting that certain aspects of development of speech motor contol are only accessible via longitudinal studies, that several other crucial aspects of that development, particularly change in absolute durations and variability can be best studied using good cross-sectional designs in which subjects are assigned to groups which are as far as possible homogeneous with respect to age, language development and background.

2.3.2. Number of subjects

Of the developmental studies reviewed in section 2.1., only three (DiSimoni,1974; Smith 1978 and Kent & Forner 1980) include more than five subjects in each child age range studied. Considerable individual differences in duration and variability measures among subjects within an age-group has been a common finding in the studies discussed; and therefore, where an experiment aims to investigate speech timing characteristics in any particular age-group, it is essential to sample as many subjects as possible within that age-group, within the limitations imposed by time constraints, to maximise the likelihood of sampling behaviours which are representative of the population as a whole at that particular age.

2.3.3. Speech data

2.3.3.1. Kind of data.

All the investigations described in section 2.1. and some in section 2.2., like the investigation reported in this thesis, are concerned with evaluating temporal variability and therefore involve multiple token speech data: the investigations by Eguchi & Hirsch; Smith, Sugarman & Long and Chermak & Schniederman involved repetitions of phrases or sentences; Tingley & Allen's subjects were required to repeat the first line of a well-known nursery song; Hawkins' study used single word data as did Catts & Jensen's study with phonologically disordered children; while those by DiSimoni and Smith used nonsense syllable data.

The merits of these various options are considered below in the light of the assumption that all investigations of spoken language performance aim, in the long run, to increase knowledge about aspects of speakers' usual spontaneous usage.

The studies by DiSimoni and by Smith used nonsense syllable data, in Smith's study subjects were simply required to repeat isolated nonsense syllables presented by live voice in random order, whereas in DiSimoni's investigation the nonsense syllables were embedded within a short carrier phrase. The children were required to isolate the nonsense syllables from the presented carrier phrase , "Say the word ......again", and repeat only the experimental syllable; a task which DiSimoni admits was difficult for many of his subjects and which therefore entailed considerable training and practice. It is questionable whether results from nonsense syllable data, especially when collected in circumstances which impose additional and extraneous requirements on child subjects as in DiSimoni's study, can be regarded as reflecting what occurs in children's usual speech production. Klatt (1976) states that,

> It is by no means certain that rules derived from nonsense syllable studies have anything to say about spontaneous speaking habits, but comparisons between measurements of, for example, Oller (1973); Lehiste (1975) on nonsense syllable sequences, Klatt (1975) and Umeda (1975) on read discourse, and Kloker (1975) on spontaneous speech suggest that the similarities are greater than the differences. (p 1209).

Although this suggests that measurements from all types of speech data can make a contribution to an understanding of spontaneous speech performance, it also suggests that there is uncertainty about the extent to which speech characteristics can be assumed to be similar across different types of data. Furthermore, it is not known whether similarities and differences across data types are the same at different ages and stages of development.

A further point arising from DiSimoni's choice of data is that some of the CVC syllables used were, in fact, **not** nonsense syllables but, by chance, formed 'real' words which were likely to be part of the spoken vocabulary of the subjects: for example, /pɪp/ and /bɪb/. It is possible that the sequences which formed familiar words prompted subjects to use different perceptual and productive strategies, introducing a possible unpredictable source of variation in the measured features.

In Hawkins' investigation 'real word' data was collected, which would seem to be likely to result in production closer to subjects' usual forms. However, in Hawkins' study, the need to find pairs of words which contrast clustered and unclustered initial consonants imposed a constraint which resulted in the choice of some words which were unlikely to have been within the spoken or comprehension vocabulary of the younger subjects; for example, words such as 'slink', 'flit', 'slit'. It is likely that the children regarded such unfamiliar words, especially in the highly 'artificial' context of being asked to repeat them in isolation, as nonsense words. Therefore, the possible difficulties associated with mixed real and nonsense word data which were discussed in relation to DiSimoni's study also apply to Hawkins'investigation. A very similar situation applies in Catts & Jensen's study with phonologically impaired and normal children, in which the choice of words was constrained by the need to contrast voiced and voiceless stop consonants in similar phonetic environments leading to the inclusion of words unlikely to be familiar to the children.

All the remaining studies described in section 2.2. involved data in the form of repeated phrases or short sentences. For example Eguchi & Hirsch elicited repetitions of the sentences, "He has a blue pen" and "I am tall", and Kent & Forner used the sentences, "We saw you hit the cat"; "The box is blue and red" and "I took the spoon and knife". While acoustic measurements from this kind of data are likely to yield results more representative of subjects' usual speech performance than those made from single word or nonsense syllable data, these sentences, repeated in isolation after the examiner (or read by older subjects) in the absence of any communicative context are probably still not particularly close to subjects' conversational forms.

Tingley and Allen adopted a different approach to the elicitation of sentence repetitions. They relied on subjects' previous knowledge of the required experimental sentence, "Twinkle, twinkle little star, how I wonder what you are." and instructed subjects to continue to repeat it until told to stop. The use of a well-known nursery rhyme seems at first sight an ingenious method of collecting speech data from young children, but on relection, it seems to entail some problems. Firstly there may have been differences in the extent to which subjects were familiar with the rhyme and this may have a bearing on the rate and stress characteristics of their repetitions. It is also likely that in this context, that is, an overlearned, highly automatized and strictly metrical utterance, speakers may show timing characteristics which are quite different from those in a their more usual spoken language forms. It is, of course, perfectly valid to choose to investigate this particular form of speech but it may not be valid to make inferences from the results about other spoken language registers.

Evidently there is no ideal or easy solution to the problem of choosing the form of multiple token data. Obviously a conversational exchange would produce the most 'natural' data, but it would be extremely difficult to obtain multiple repetitions of items in the same phonetic context in such a setting. It is suggested in the light of this review of the options that within the limitations imposed by a particular area of study, speech data should be as near as possible to subjects' spontaneous, usual forms. That is, that 'real' words should be used in preference to nonsense words; connected speech data should be used in preference to single-word data and that uncontrolled mixing of say 'real' and nonsense words should be avoided. Since continuous, conversational speech data does not seem a viable option when multiple tokens are required, it is suggested that sentence repetitions offer the best compromise. It may be possible, by manipulating the content of the sentences and the way in which they are presented, to avoid an extrememly artificial experimental situation in which children are required to repeat rather uninteresting sentences after an examiner. These data collection issues are addressed below (section 2.3.4.).

2.3.3.2. Number of tokens.

The various studies described in sections 2.2. and 2.3. differ widely in the number of tokens of experimental items which are analysed. For example, Eguchi & Hirsch elicited five repetitions of two different sentences from their subjects and Kent & Forner analysed four tokens of each of three sentences from each subject; Tingley & Allen, however, collected thirty repetitions of their nursery rhyme data. Some of these differences among studies can be accounted for by the different emphases of the investigations; that is, not all of them are primarily concerned with intra-subject context-free variability. However, even in studies where this is not the main concern, investigators have reported results for intra-subject variability, sometimes on the basis of rather limited data. For example, although Eguchi & Hirsch's investigation examined change in a variety of phonetic characteristics of speech with age, they suggest that the result of greatest interest was the "change in precision or reproducibility of certain aspects of speech sounds" with age, (p.44); that is, the results pertaining to intra-subject context-free variability. However their findings on individual

variability are based on measurements from only five tokens of each of the two experimental sentences. That is, conclusions on age related changes in articulatory precision are drawn from "intra-subject standard deviations of the distribution of five repetitions within each age group" (Eguchi & Hirsch, 1969, p 7), and it is questionable whether much weight can be given to conclusions drawn on the basis of measures of central tendency and variance for such small samples.
DiSimoni's study, in which only three tokens of each nonsense syllable were elicited from each subject, further emphasises that if context-free intra-subject variation is to be compared across age-groups it is essential to collect a large number of tokens from each subject. As discussed above, DiSimoni's main concern was with developmental trends in context-conditioned durational variability, but he also reports results for change in context-free variability over the age range studied. His conclusion that speaker variability declines with age is drawn on the basis of measurements pooled across subjects within an age group and across different phonetic contexts and must therefore be viewed with some caution.

The desirability of working with large numbers of tokens when making measures of individual central tendency and variance is obvious since it helps to ensure that the data is representative of a subject's usual range of behaviours and that measures are not disproportionately affected by extreme values. Of course, the number of tokens of experimental utterances must also be decided in the light of practical considerations of collection time, analysis time and subjects' tolerance and attention span. A further consideration is that the collection of large numbers of tokens of a word or sentence, as for example in Hawkins' and in Tingley & Allen's studies, is likely to have repercussions on the 'naturalness' of the data; that is when subjects (perhaps particularly child subjects) are required to produce large numbers of repetitions they may tend to do so in a 'rote' fashion, in which utterances become progressively more devoid of meaning for the speaker and tend to deviate more and more from their usual forms. Choice of the number of tokens to be collected in a particular investigation must be a compromise decision in which all these factors are considered, and any decision must be evaluated with respect to the particular data and subjects concerned by conducting pilot data-collection trials.

2.3.4. Data collection procedure.

2.3.4.1. Consistency of presentation and procedure.

In investigations of age related change in performance it is essential to maintain, as far as possible, identical experimental conditions across all age groups of subjects to avoid the possibility of introducing experimental factors which could confuse the interpretation of results. This requirement has not always been met in the studies described above.

For example, in Eguchi and Hirsch's study different data collection procedures were used for different subject groups; adults and children over seven years of age were asked to read the experimental sentences, but younger children were required to repeat the sentences after an adult speaker. Thus the communicative context in which the speech data was elicited was quite different for different age groups and may have introduced stylistic differences relating to stress and intonation which affected the phonetic characteristics under investigation.
Furthermore, since the younger children were required to perform an essentially imitative task they may have tried to reproduce the characteristics of the stimulus sentences. Since these were 'live voice' presentations there may have been variation in the presentation of the stimuli, within and between subjects, in terms of the relevant phonetic features which affected the measured parameters. A similar criticism can be levelled at Hawkins' data collection procedures; again, adult subjects were required to read the experimental words while child subjects repeated the words after the examiner. In the first phase of the study some attempt was made to present the words to the children in a meaningful (story) format before requiring them to repeat the words. In the second phase, with the same children 14 months later, the story format was abandoned and the children were simply required to repeat the words from a list. Thus, as in Eguchi & Hirsch's study there were factors in the design of this investigation which could have introduced unpredictable sources variation in performance.

In Kent & Forner's study the data collection procedure was consistent in that the data were elicited in the same way from all groups of subjects, that is, by repetition after live-voice presentation. However, as discussed above, since subjects are being presented with an essentially imitative task, the use of live presentation of the experimental sentences may introduce a source of variation between subjects. That is, durational variations in the stimuli have the potential to influence the durational charateristics of the collected data. There may be particular danger when a large age range of subjects is involved as in Kent and Forner's investigation because adults may adopt different speaking rates and different stress and intonation patterns when speaking to younger and older listeners (Schiff-Myers, 1988).

In Smith's description of his method he acknowledges some of the problems involved in collecting multiple token speech data from three and four year olds and recognises the desirability of consistency of presention of stimulus material. In his pilot study Smith used tape-recorded stimuli presented to subjects via headphones. However, he found that, "the lack of child - experimenter interaction seemed to inhibit (the children's) interest and often resulted in very inaccurate repetitions of stimuli." The tape-recorded approach was subsequently abandoned in favour of live-voice presentations by the experimenter.
In view of Smith's experiences it seems that a method of data collection which allows consistent stimulus presentation (that is, using taped material) but within an interactive setting which motivates child subjects and maintains their attention is likely to be most successful.

In Catts & Jensen's study in which single word data was collected from phonologically disordered and normal children between the ages of 3;10 - 5;7 years, an ingenious data-collection procedure was followed which seems to overcome many of the problems identified in other studies. This procedure involved hiding a 'reinforcer' (a penny or a sweet) under a picture card of one of the required items. The examiner asked "Where is the penny" and subjects were trained to reply with a complete sentence of the form, "The penny is under the .....".

2.3.4.2. Instructions to subjects.

In most of these investigations the authors do not report the precise instructions which were given to subjects during the data collection procedure. Tingley & Allen however report that their subjects were asked to repeat the sentence at regular intervals, controlled by the experimenter, and to, 'Say the sentence the same way each time at whatever speed is comfortable'. This instruction specifically focuses subjects' attentions on speech rate and on maintaining a constant speech rate. It could be argued that if subjects are actively trying to maintain a stable rate of speech any temporal variation observed can be regarded as a true reflection of a subject's speech motor control ability; but, particularly when child subjects of various ages are involved, the effects of such an instruction are unpredictable and may vary between subjects. That is, the youngest children may be unable to understand fully the wording of the instruction and therefore ignore it, or they may lack the necessary metalinguistic awareness to apply the instruction to their own speech production. Thus such an instruction is likely to add another uncontrolled source of variation to the data without necessarily removing the (unavoidable) variation which results from inherent differences in individuals' speaking styles. On balance, it is probably best to avoid drawing subjects' attention to the timing aspects of their utterances during the collection of data. Exceptions are of course studies in which speech rate is manipulated as an experimental variable.

2.3.5. Data analysis.

2.3.5.1. Selection of data for analysis.

In two of the studies described, specific reference is made to the selection of data for analysis from the corpus of data collected. Tingley and Allen collect a large number of tokens (thirty) of their experimental sentence from each subject. They report that the data was smoothed prior to analysis by excluding repetitions in which there was a noticeable dysfluency, cough, laugh or swallow. It seems essential that criteria are set to exclude such categories of hesitant tokens in any study which measures utterance duration and variability of duration to ensure that results are not affected by extreme values which result from such large time-scale disruptions. In Smith's study however a much more radical selection procedure is employed: an unspecified number of tokens of nonsense syllables were collected from each subject and "those productions which were judged to be the best ten" were selected for analysis, (p.46). Such a selection procedure could invalidate measures of intra and inter-subject variability by masking the true extent of variation which occurred in the data, and is therefore not considered advisable in any experiment which investigates variability.

2.3.5.2. Measures of intra-subject variability.

Several of the papers cited include discussion about the most approporiate measure for assessing durational variability. Kent and Forner devote considerable space to this consideration and their conclusions have influenced the choice of measures used in the experiment reported below. The discussion centres on the extent to which variability of duration depends on absolute (mean) durational values. To investigate this relationship Kent and Forner prepared scattergrams for selected segment duration measures plotting the relationship between individual subject's standard deviation and mean values. Correlation coefficients and levels of statistical significance were derived. For the two segmental measures reported, the correlation between mean and standard deviation was found to be significant at the 0.05 confidence level. Kent and Forner conclude that, " at least part of the variance in duration measures is related to speaking rate, given that speaking rate determines segment durations. The younger children had slower speaking rates (hence longer segment durations) and therefore greater variability, both as a group as well as individually",(p.164). They therefore argue that comparing subjects with respect to a **relative** measure of variation, the coefficient of variation (standard deviation / mean) is more appropriate and gives a more meaningful assessment of variability than using a measure of absolute variance.
Tingley & Allen and Eguchi & Hirsch also choose to use a measure of relative variance in their reporting of results on intra-subject variability.

2.3.6. Level of phonological acquisition in child subjects and the phonological form of the data.

Most of the authors whose studies are reviewed above provide very little information concerning the status of their child subjects' articulatory / phonological development. The children in Kent & Forner's investigation "were judged to be free of speech disorders and had successfully completed a task of speech sound imitation that required basic listening and articulatory skill" (Kent & Forner, 1980, p 159); the child subjects in Tingley and Allen's study were screened using the 'Arizona Articulatory Proficiency Scales', but other investigators either make no reference to the stage of phonological acquisition reached by their subjects or state only that subjects were judged to be free of speech and language disorders. Catts & Jensen's study is an exception since it deals with phonologically disordered children, but even in this investigation only a numerical, articulation attainment test score is given without any descriptive analysis of the phonological form of the data collected in the experiment.

Several of these studies, for example Eguchi & Hirsch, include subjects as young as 3 -4 years of age and yet authors do not report subjects' developmental level of speech acquisition. This is a surprising omission since it would be unlikely that all tokens of all the experimental utterences collected from such young children were fully adult-like in phonological form, given that the occurrence of simplifying phonological processes is very common in the speech of normally-developing children at these ages. (Grunwell 1987; Stoel-Gammon & Dunn 1985). Two explanations are suggested. It is possible that experimenters collected more tokens of experimental words and sentences than were included in their analyses, that is, they rejected any tokens which were non-adult like in phonological form. Smith (1978) makes this explicit in the description of his methodology (see section 2.3.5. above.) Another possible explanation is that experimenters selected for inclusion in their youngest age-groups children who were more mature than average in terms of phonological / articulatory development. Such a strategy would in fact be valid in the context of the reviewed studies since it would tend to work **against** finding clear age-related trends.

Even if all subjects in the above investigations had fully adult-like phonological systems there would still be the possibility that not all tokens were spoken in citation form, particularly in investigations involving phrase and sentence data. It is surprising that in none of these studies any reference is made to the phonological form of the tokens collected from child and adult subjects. To consider one example more or less at random from those studies in which sentence repetitions were required; the sentence "I took the spoon and knife" was one of four sentences included in Kent & Forner's data, and it is possible that some speakers would use reduced, connected speech forms in such a sentence, (the diphthong of the word 'I' might be reduced, and the word 'and' might be reduced to a neutral vowel + nasal). It is also possible that the use of such connected speech forms may have varied between age groups, between subjects within an age group and even between repetitions of a sentence by an individual subject. If such variations of phonological form were present in the data from this and other studies, but were not considered in the analysis of the data, the interpretation of results on mean phrase duration and variability of phrase duration becomes very difficult, since it is possible that durations were not always measured over the same number of speech segments. It would seem highly desirable to analyse and take into account the phonological form of data in investigations concerned with mean duration and variability of duration.

CHAPTER THREE

FIRST PHASE OF THE INVESTIGATION: ADULT AND NORMAL CHILD SUBJECTS

As outlined in the introduction to the thesis, the investigation examines speech motor control in adult speakers, normally developing pre-school children and in phonologically delayed pre-school children, using temporal acoustic analysis and perceptually based analysis of multiple token speech data. The first phase of the study compared data from adult and normal child subjects and the second phase compared data from phonologically delayed child subjects with the results from the first phase.

This chapter describes the method and reports and discusses the results of the first phase of the investigation (experiment one). The first section of the chapter states the aims of the experiment and the method is described in section 2. The third section reports the results of temporal acoustic analysis; results of perceptual analysis of the data are reported in section 4 and the fifth section reports results of a measure of speech rate which takes account of the phonological structure of the data . In the final sections of the chapter the results are summarized and discussed and applied to the design of the second phase of the investigation, involving phonologically delayed child subjects, which is reported in Chapter Four.

3.1. AIMS

This first experiment aimed to compare speech motor control in young normally-developing children and in adult speakers by examining timing characteristics and phonological form in multiple sentence repetitions. On the basis of previous investigations measurements of mean phrase and segment durations, measurements of intra-subject temporal variability and measurements of mean speech rate were selected as indices of speech motor control ability. This first experiment aimed to determine, in the context of a particular experimental phrase, whether and in what precise ways these measures distinguished between mature adult speakers and normally developing child speakers.

That is, the first experiment was designed to determine:
(i) whether adult and young normally-developing child subjects exhibit significant differences in mean phrase and segment durations in multiple repetitions of a particular experimental utterance;

(ii) whether there are significant differences in individual and group variability of phrase and segment durations between the young children and adult speakers in this particular context;

(iii) what similarities and differences of phonological form can be observed in the speech data from adult and normal child subjects;

(iv) what relationships exist among measures of duration, variability of duration and phonological form in the data and whether these relationships are similar in the data from young children and adults;

(v) whether a measure of speech rate which takes account of the phonological form of the data provides a better indication of speech motor ability than a straightforward measure of mean utterance duration.

3.2. METHOD

3.2.1. Subjects

The subjects for this experiment were 12 adults (Group A) and 12 preschool children who were developing speech without apparent difficulty (Group N).

3.2.1.1. The child subjects.

The child subjects were preschoolers who attended a playgroup situated on the premises of a state primary school in a suburb of Edinburgh. The group consisted of four girls and eight boys with an age range between 3;8 and 4;10 years (mean 4;3 years).

In the first instance the playgroup leader asked all parents of children in the required age range (3;6 - 5 years) if they would be willing for their children to take part in the study.
Seventeen families were contacted at random from the list of positive responses. Of these, fifteen subsequently kept appointments with the investigator. Two of the seventeen were unable to attend, in one case because the child was ill and in the other case because of the mother's work commitments.

The twelve children selected to take part in the experiment met the following criteria: they had normal hearing , that is, they had passed all routine screening assessments of hearing; they had never been referred to a speech therapist and were considered by their parents and playleaders to be acquiring spoken language without apparent difficulty; they obtained a Standard Score of above 100 on the Edinburgh Articulation Test (EAT) (Anthony, Bogle, Ingram & McIsaac, 1971), and their speech exhibited only those simplifying phonological processes which would be expected in normally developing children of the same age, (cf: Grunwell, 1982, p 184 and Stoel-Gammon and Dunn, 1985, p 43).
The children belonged to families which were local to the Lothian / Fife region of Scotland. English was the only language spoken in their homes and parents spoke with the local Scottish accent of English.

Three of the fifteen available children proved to be unsuitable for inclusion in the experiment: one child was excluded because his standard score on the EAT was below 100; another because his mother reported that he had a history of mild intermittent hearing loss associated with upper respiratory tract infections and otitis media and a third child was excluded because he could not be persuaded to co-operate in the data collection procedure.

Table 1, below, shows the age, sex and standard score on the Edinburgh Articulation Test for each of the 12 normal child subjects (N1 - N12).

See Appendix 1A for an analysis of the occurrence of simplifying phonological processes for each N Group subject made on the basis of the EAT data.

Ref.No.	Sex	Age	EAT Standard Score
N1	M	4;10	110
N2	F	4;9	141
N3	M	4;9	103
N4	M	4;6	127
N5	M	4;6	116
N6	F	4;5	129
N7	F	4;3	119
N8	M	4;1	141
N9	M	3;10	117
N10	M	3;10	103
N11	F	3;9	139
N12	M	3;8	125

Table 1. Reference numbers, age, sex and EAT scores - N Group.

3.2.1.2. The adult subjects.

The adult subjects were members of the non-teaching staff or mature first year students at Queen Margaret College, Edinburgh who volunteered to assist with the project. They had no knowledge of the nature of the experiment except that it involved the collection and analysis of speech samples.

The group consisted of seven female and five male subjects with an age range between 22 and 55 years. The subjects all belonged to the local speech community, that is, they were resident and had been brought up in the Lothian or Fife regions of Scotland and spoke with the local Scottish accent of English.
All adult subjects were judged by the experimenter to be free of speech disorders.

Table 2, below, gives reference numbers and sex for each of the Group A subjects.

Ref.No.	Sex
A1	F
A2	F
A3	F
A4	F
A5	F
A6	M
A7	M
A8	F
A9	M
A10	M
A11	F
A12	M

Table 2. Reference numbers and sex - A Group

3.2.2. Data and the data collection procedure.

The data were chosen and the data collection procedure was designed in the light of methodological issues arising from an examination of related previous studies as discussed in Chapter Two.

Prior to the main investigation, a small scale pilot study was carried out involving three phonologically delayed children who were attending the speech therapy clinic at Queen Margaret College. The subjects were two boys aged 3;11 years and 5;1 years and one girl aged 4;3 years. The aims of the pilot study were:

(i) to assess the appropriateness of the chosen experimental phrase and carrier sentences to the age and interests of the subjects;

(ii) to assess the appropriateness of the stimulus materials and to find the most successful data collection method;

(iii) to determine how many repetitions of the experimental phrase could be elicited from the children without loss of motivation and co-operation;

(iv) to determine optimum positioning for the recording equipment, height of seating for the subjects and positioning of the child and examiner during data collection.

Evaluation of the outcomes of the pilot study led to finalisation of the data collection method and materials described below.

3.2.2.1. Data sample.

The speech data collected from each subject consisted of 18 tokens of the same phrase incorporated in similar phonetic environments within three different carrier sentences.
The sentences were chosen to be easily illustrated and appropriate to the likely interests, experience and vocabulary of pre-school children in the Edinburgh area.

The experimental phrase was:
' two wee boys are playing in the '.

The carrier sentences were:
' Two wee boys are playing in the sand.'
' Two wee boys are playing in the sea.'
' Two wee boys are playing in the snow.'.

3.2.2.2. Recording equipment and recording conditions.

Speech data were recorded in a sound-proof studio in the clinical phonetics laboratory of Queen Margaret College.
Recording equipment consisted of a studio quality Neumann U47 condenser pressure-gradient microphone and a Sony 'Video 8' digital audio/video cassette recorder.
A technician assisted at all recording sessions.

3.2.2.3. Materials used in the collection of the speech data.

A 'Language Master' system (71713X), (Bell & Howell) was used in the collection of the speech data. The system can be used to present pre-recorded spoken material simultaneously with an illustration in a manner which holds the attention of young children.
The Language Master system consists of a recording and playback unit

with built-in microphone and speaker and sets of cards (37x9cms) on which pictures can be drawn. Each of these cards can carry up to ten seconds of audio information on a magnetic tape strip which runs along the lower edge of the card.
When placed in a slot on the Language Master Unit a card is automatically moved from left to right and as it moves through the unit a recording can be made on to the magnetic strip or pre-recorded material can be played back.

Recordings of the investigator saying the experimental sentences were made on to Language Master cards. Nine cards were prepared, each carrying a recording of one of the sentences. That is, each of the three sentences was represented three times on separate cards. Each card also carried an illustration of the relevant sentence. Representations of each of the three different illustrated Language Master cards can be found in Appendix 2.

3.2.2.4. Data collection sessions.

In the data collection procedure each of the nine 'Language Master' cards was used twice, giving a total of eighteen presentations. Subjects were introduced to the three different picture cards and were told that they would see a card move through the Language Master unit and that they should listen to the voice on the tape and then tell the investigator what the voice had said.
At each presentation of a card , after the recorded voice and while the picture card was still moving through the unit, the investigator told the subject to, "Wait until the card stops moving and then tell me what you heard". It was found that an instruction to, "Wait until the card stops moving and then tell me what the lady said", was more suitable for some of the child subjects.

This method of presentation ensured that the motor noise from the Language Master unit did not interfere with the quality of recording of the subjects' responses and ensured a fairly uniform time delay between presentation and response. A further consideration was that the presentation should promote a fairly 'natural' context for the subjects' repetitions of the experimental sentences; that is, subjects were asked to 'report' what they heard to the investigator rather than being required to produce an accurate imitation of the

stimulus.
Each of the nine picture/audio cards was presented twice so that eighteen tokens of the experimental phrase were recorded for each subject (a total of 216 tokens for each subject group).

It was explained to the adult subjects that the materials and procedure had been designed with young children in mind. All adult subjects accepted this explanation.

Parents of the child subjects were encouraged to remain with their children throughout the data collection sessions.
The session began with a few minutes conversation with the child and parent, usually centred on toys which the child had chosen. This helped to put the child at ease in the environment of the recording studio and allowed the technician to adjust the recording equipment to the child's voice level. The time spent in play and conversation varied; some children required only 4 or 5 minutes to settle into the situation while others needed up to 15 minutes before being ready to participate.

In order to make the data collection procedure more interesting for the child subjects a guessing game format was adopted as follows: after the first card had been presented twice the remaining cards were placed face down in a box and the child was invited to guess which picture would be next and then to turn up the card to see if the guess had been correct. The investigator and parent also became involved in the guessing game.

3.2.3. Analysis

3.2.3.1. Instrumentation.

Acoustic analysis was carried out using a Kay Digital Sona-graph 7800 and Sona-graph printer 7900 interfaced via a Kay interface 7812-488 with a Hewlett Packard Vectra Computer, using a software package designed and written by C. Watson of Queen Margaret College Clinical Phonetics Laboratory.

3.2.3.2. Capture and storage of the data for analysis.

Each token of the experimental phrase was transferred from the digital audio-recording to the Sona-graph and redigitised for transfer to the Vectra Computer where it was stored under a file name which specified the subject's initials and the number of the token (1 -18) in the subject's data sample.

3.2.3.3. Temporal acoustic measurements.

For each token of the experimental phrase a wide-band spectrogram was made with a scale of 10 ms/division on the time axis. An example is given in figure 6, below.
The following measurements were made from each spectrogram (measurements were made in milliseconds to an accuracy of 2.5 ms):

(i) total duration of the phrase
(ii) duration of labial closure for the initial plosive in the word 'boys'
(iii) duration of labial closure for the initial plosive in the word 'playing'
(iv) duration of the vowel in the word 'boys'
(v) voice onset time (VOT) of the initial plosive in the word 'two'
(vi) VOT of the initial plosive in the word 'boys'
(vii) VOT of the initial plosive in the word 'playing'.

The criteria applied in making the temporal measurements were as follows:
(i) total phrase duration was defined as the interval between abrupt onset of energy associated with release of closure for the initial plosive consonant in the word 'two' and termination of energy in the second and third formants of the vowel in the word 'the'.
(ii) closure durations of plosive consonants were defined as intervals from offset of the preceeding vowel segment to the sudden onset of a burst of energy resulting from release of closure for the plosive.
(iii) vowel duration was defined as the interval between onset of periodic energy forming the commencement of formant patterns and the abrupt fall-off in energy in second and third formants. In tokens where formant bands were seen to continue into the following fricative segment the onset of friction was taken to be coincident

with the offset of the vowel.
(iv) voice onset time measures were defined as intervals between sudden onset of energy associated with release of stop closure and onset of periodic low frequency energy clearly associated with the following vowel segment.
When VOT is defined in this way only positive (or zero) VOT values are possible. In tokens where some periodic low frequency energy was apparent during consonant closure, continuing from the preceeding vowel, this was disregarded when making VOT measurements provided that a discontinuity could be identified before the onset of voicing associated with the vowel following the stop consonant.

Whenever difficulties were encountered in making a measurement from a 10 ms/division spectrogram one or both of the following additional procedures were followed: an expanded wide-band spectrogram (5 ms/division on the time axis) was made on the Sona-graph printer and/or the token was analysed using the 'Sonsoft' system which gives a VDU display of the analogue waveform of the utterance and a colour-contour spectrogram in which energy is displayed as a colour series from white (least energy) through brown, yellow, blue, green and red (most energy). The system incorporates cursors which can be moved along the time axis of the wave-form and contour spectrogram displays. The system then displays the time interval (in ms) between the leading edges of the cursors allowing temporal measurements to be made.
The criteria employed in making the temporal measurements from the computerised contour spectrograms were established on the basis of extensive comparisons with measurements made from conventional printed spectrograms using pilot study data.

Some tokens were excluded from one or more of the temporal measurements because the above criteria could not be strictly applied. That is:
(i) tokens were excluded from the measure of mean phrase duration if hesitations, coughs or pauses for intake of breath were apparent;
(ii) tokens were excluded from measures of segmental mean durations if a hesitation or other disruption was judged to affect a particular segment of the utterance;
(iii) tokens were excluded from measures of mean consonant closure

duration and mean voice onset time if no burst of energy marking release of closure could be identified. This occurred in cases where closure for a stop consonant was extremely lax or incomplete and in cases where a speaker employed another manner of articulation in their realisation of a target stop consonant.

3.2.3.4. Perceptual analysis / transcription.

A broad phonetic transcription of each token of the experimental phrase was made by listening to the digital audio recording. By examining the printed spectrograms for discontinuities associated with segment boundaries, the phonetic transcription was written below the base line of the spectrogram .
Figure 6 shows an example of a printed spectrogram including a phonetic transcription and markers for temporal measurements.

Subject A11 (GC)

Token 2 (sand)

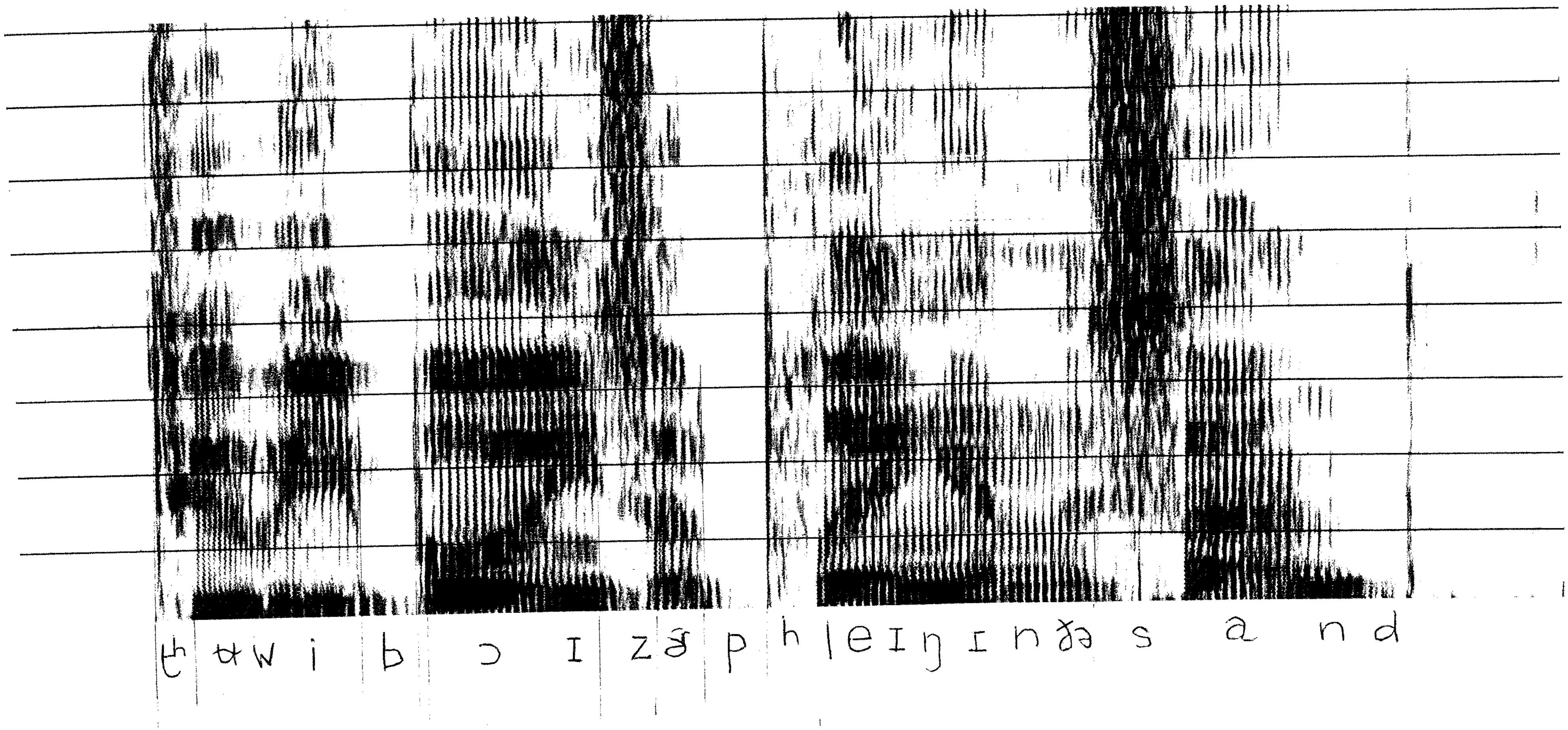

Figure 6 Example of printed spectrogram.

3.2.3.5. Statistical analysis.

For each subject the range, mean, standard deviation and coefficient of variation (standard deviation / mean) were calculated for each measured temporal feature.

The values obtained for the mean, standard deviation and coefficient of variation for each of the five measures for each of the 12 subjects in each group were entered into a computerized statistical package (SPSS - 1988, Chicago) and group means, group standard deviations and significance levels of the difference between group means for each of the five temporal measures were derived.

3.3. RESULTS OF TEMPORAL ACOUSTIC ANALYSIS

This section reports the results of the temporal acoustic measures made on the speech data from the adult and normally developing child subjects as described above.

3.3.1. Measures of phrase and segment durations and temporal variability.

3.3.1.1. Mean phrase duration and variability.

In the adult data, two hesitant tokens were excluded from this measure; one token from subject A3 and one from subject A6. Twelve N Group tokens were also excluded because of hesitations; N3 (1); N5 (2); N6 (2); N8 (1); N10 (2) and N11 (4). A further two N Group tokens were excluded from all measures because noise on the recording made accurate acoustic measurement impossible; N2 (1) and N3 (1).

Figure 7 displays the distribution of phrase durations across all included tokens from the adult and normal child subjects.
The figure shows that 63 N Group tokens were of longer duration than any of the adult tokens and that 8 N Group tokens were of shorter duration than any found in the adult data; that is, there was a greater spread of phrase duration values in the child data compared with the adult data, with a tendency towards longer durations in the child data.

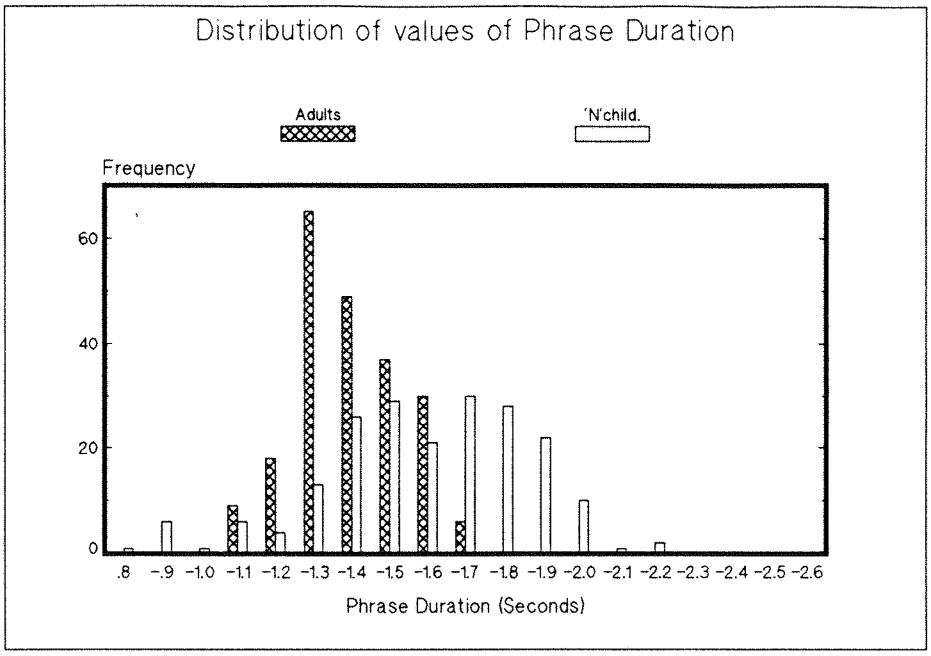

Figure 7. Distribution of phrase duration values - A and N Groups

Tables 3 & 4 show individual subjects' ranges, means, standard deviations and coefficients of variation for the duration of the experimental phrase and also group mean values for mean duration and coefficient of variation. The tables show that adult subjects' mean phrase durations ranged from 1106 - 1531 ms with a group mean of 1340 ms and the range for the child subjects was 1113 - 1801 ms (group mean 1554 ms). Seven of the child subjects had individual mean phrase durations which were longer than any of the adult subjects' while the remaining five child subjects fell within the adult range. That is, there was greater within-group intersubject difference in mean phrase duration in the child group than in the adult group, and the group mean value was higher in the child group. A t-test was used to evaluate the difference between the group means and this difference was found to be statistically significant ($p < .01$). Individual coefficients of variation for adult subjects ranged from 0.031 - 0.070 (group mean 0.044) and for child subjects from 0.072 - 0.148 (group mean 0.113). There was no overlap between the ranges for the two groups and a t-test confirmed that the difference between the group mean values of 'C' was highly statistically significant ($p < .001$).

SUBJECT*	RANGE (ms)	MEAN (ms)	S.D.(ms)	C (SD/M)
A1	1220-1390(170)	1316	48	0.036
A2	1195-1330(135)	1254	40	0.032
A3(17)	1250-1550(300)	1378	97	0.070
A4	1150-1490(340)	1265	80	0.063
A5	1410-1670(260)	1531	75	0.049
A6(17)	1300-1440(140)	1369	44	0.032
A7	1030-1240(210)	1106	68	0.061
A8	1335-1610(275)	1428	76	0.053
A9	1335-1550(215)	1444	45	0.031
A10	1155-1330(175)	1234	49	0.040
A11	1170-1320(150)	1229	42	0.034
A12	1450-1620(170)	1529	48	0.031

Group mean phrase duration = 1340 ms
Group mean coefficient of variation = 0.044

* Number of tokens given in brackets if fewer than 18.

Table 3. Duration and variability of duration of the experimental phrase - A Group subjects.

SUBJECT*	RANGE (ms)	MEAN (ms)	S.D.(MS)	C (SD/M)
N1	1430-1905(475)	1717	140	0.082
N2	1440-2110(670)	1769	165	0.093
N3(17)	1325-1950(625)	1694	161	0.095
N4	1220-1780(560)	1426	137	0.096
N5(16)	1505-1925(420)	1721	124	0.072
N6(16)	1255-1930(675)	1533	196	0.128
N7	1345-1970(625)	1670	162	0.097
N8(17)	1360-1785(425)	1525	121	0.079
N9	795-1495(700)	1113	247	0.222
N10(16)	900-1550(650)	1225	181	0.148
N11(14)	1480-1970(490)	1801	176	0.098
N12	1185-1995(810)	1453	214	0.147

Group mean phrase duration = 1554 ms
Group mean coefficient of variation = 0.113

* Number of tokens given in brackets if fewer than 18.

Table 4. Duration and variability of duration of the experimental phrase - N Group subjects.

Figure 8, below, displays individual mean durations, bracketed by standard deviations, with coefficients of variation above each bracket; that is, it illustrates the marked difference in intrasubject variability of phrase duration between the adult and child subjects.

Thus, in summary, the measures of mean phrase duration and variability of phrase duration resulted in statistically significant differences between the adult and child subjects in the direction of longer mean durations, greater inter-subject variability and greater intra-subject variability among the child speakers.

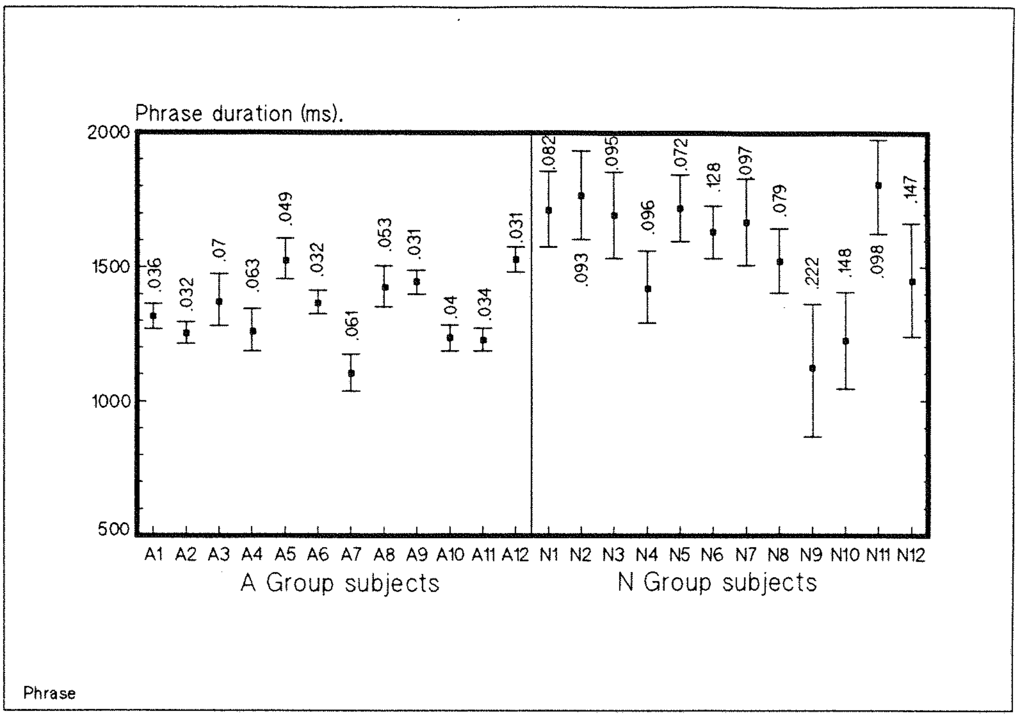

Figure 8. Mean duration and variability of duration of the experimental phrase - A & N Group subjects.

3.3.1.2. Mean duration and variability of closure of the initial consonant in the word 'boys'.

One adult token (from subject A3) was excluded from this measure because a hesitation affected the duration of this consonant closure duration. A further adult token (from subject A7) was excluded because the target segment /b/ was realised as a bilabial nasal /m/. 26 N Group tokens were excluded because no burst of energy associated with release of closure was visible on either the spectrogram or waveform displays. These were:
1 token from subject N3 (/b/ -> [β]),
2 tokens from N5 (/b/ -> [β], [w]),
2 tokens from N6 (/b/ -> [b̚]),
6 tokens from N8 (/b/ -> [b̚], [v], [w]),
8 tokens from N9 (/b/ -> [v], [ʋ], [β]),
1 token from N10 (/b/ -> [ʋ]),
6 tokens from N12 (/b/ -> [b̚], [w]).

Figure 9 displays the distribution of all measurable values of the closure duration of /b/ across all Group A and Group N tokens. The figure shows a marked trend towards longer durations among the N

Group tokens compared with adult values. That is, although only 11 N Group tokens exhibited closure durations for this consonant which were above the adult range of values it can be seen that while only 2 adult tokens had closure durations above 100 ms there were 70 N Group tokens which fell into this category.

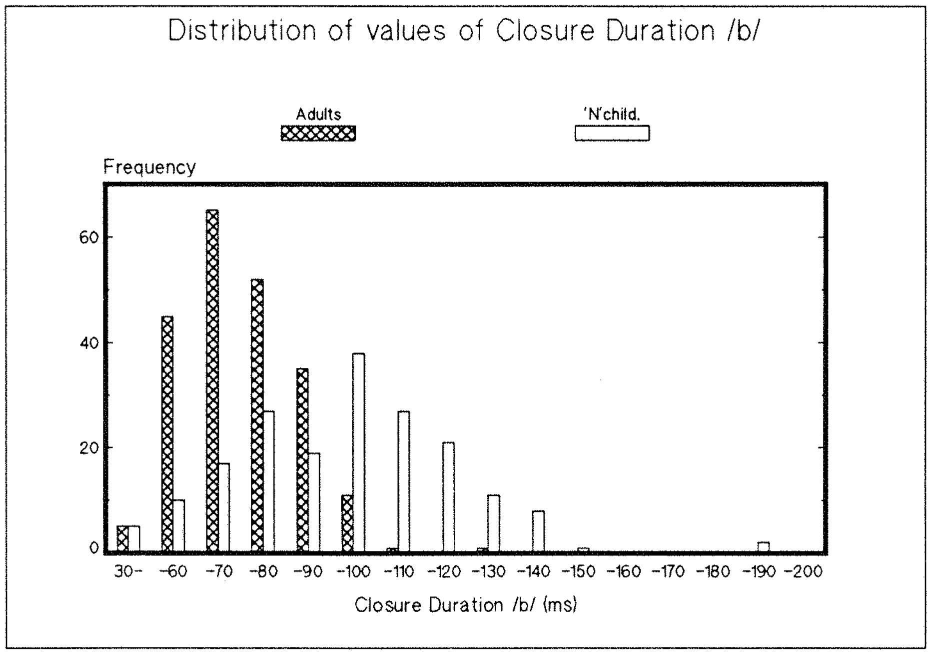

Figure 9. Distribution of closure duration values for /b/ in the word 'boys' - A & N Groups.

Tables 5 & 6 show individual subjects' ranges, means, standard deviations and coefficients of variation for this measure and also group mean values for mean duration and coefficient of variation. Referring to these tables it can be seen that mean closure duration for individual adult subjects ranged from 61 - 89 ms (group mean 74 ms), while the range for the child subjects was 69 - 117 ms (group mean 95 ms). Only three of the child subjects' mean closure durations were within the adult range and the remaining nine child subjects exhibited mean closure durations above the upper extreme of the adult range. Hence the group mean value for this closure duration was higher in the child group than in the adult group and there were greater within-group intersubject differences in mean closure among child subjects than among adult subjects. A t-test confirmed that the difference between group means was statistically

significant at the 0.1% level ($p < .001$).
The child subjects exhibited greater individual (intra-subject) variability on this measure than the adult subjects (tables 5 & 6 and figure 10). The range of adult values for the coefficient of variation 'C' was 0.082 - 0.146 (group mean 0.105) and the range of N Group values was 0.121 - 0.390 (group mean 0.234) (see tables 5 & 6). While three children had coefficients of variation which fell within the adult range, the remaining nine children had values for 'C' above the upper extreme of the adult range. A t-test confirmed that the difference between the group mean values for 'C' was statistically significant at the 0.1% level ($p < .001$).

SUBJECT*	**RANGE (ms)**	**MEAN (ms)**	**S.D.(ms)**	**C (SD/M)**
A1	75-95 (20)	85	7	0.082
A2	50-85 (35)	66	9	0.136
A3(17)	70-125 (55)	89	13	0.146
A4	60-85 (25)	71	8	0.112
A5	60-85 (25)	72	7	0.097
A6	75-100 (25)	89	8	0.090
A7(17)	50-70 (20)	62	6	0.097
A8	60-90 (30)	75	7	0.093
A9	70-95 (25)	82	7	0.085
A10	60-90 (30)	69	10	0.144
A11	50-70 (20)	61	6	0.098
A12	50-70 (20)	64	5	0.078

Group mean closure duration = 74ms
Group mean coefficient of variation = 0.105

* Number of tokens given in brackets if fewer than 18.

Table 5. Duration and variability of duration of closure for /b/ in the word 'boys' - A Group.

SUBJECT*	RANGE (ms)	MEAN (ms)	S.D.(ms)	C (M/SD)
N1	80-140 (60)	117	16	0.137
N2	90-130 (40)	107	13	0.121
N3(17)	60-135 (75)	106	23	0.217
N4	55-110 (55)	83	14	0.169
N5(16)	65-140 (75)	94	21	0.223
N6(16)	60-190 (130)	100	39	0.390
N7	55-130 (75)	98	19	0.194
N8(12)	45-120 (75)	85	22	0.259
N9(10)	40-110 (70)	69	26	0.377
N10(17)	60-140 (80)	101	28	0.277
N11	70-110 (40)	90	11	0.122
N12(12)	50-150 (100)	93	30	0.323

Group mean closure duration = 95 ms
Group mean coefficient of variation = 0.234

* Number of tokens given in brackets if fewer than 18.

Table 6. Duration and variability of duration of closure for /b/ in the word 'boys' - N Group.

Figure 10, below, displays individual means, bracketed by standard deviation, with coefficients of variation above each bracket; that is, it illustrates the marked difference in intrasubject variability of closure duration between the adult and child subjects.

In summary, the measures of mean closure duration and variability of closure duration for the initial consonant in the word 'boys' resulted in statistically significant differences between the adult and child subject groups in the direction of longer mean durations, greater inter-subject variability and greater intra-subject variability among the child subjects.

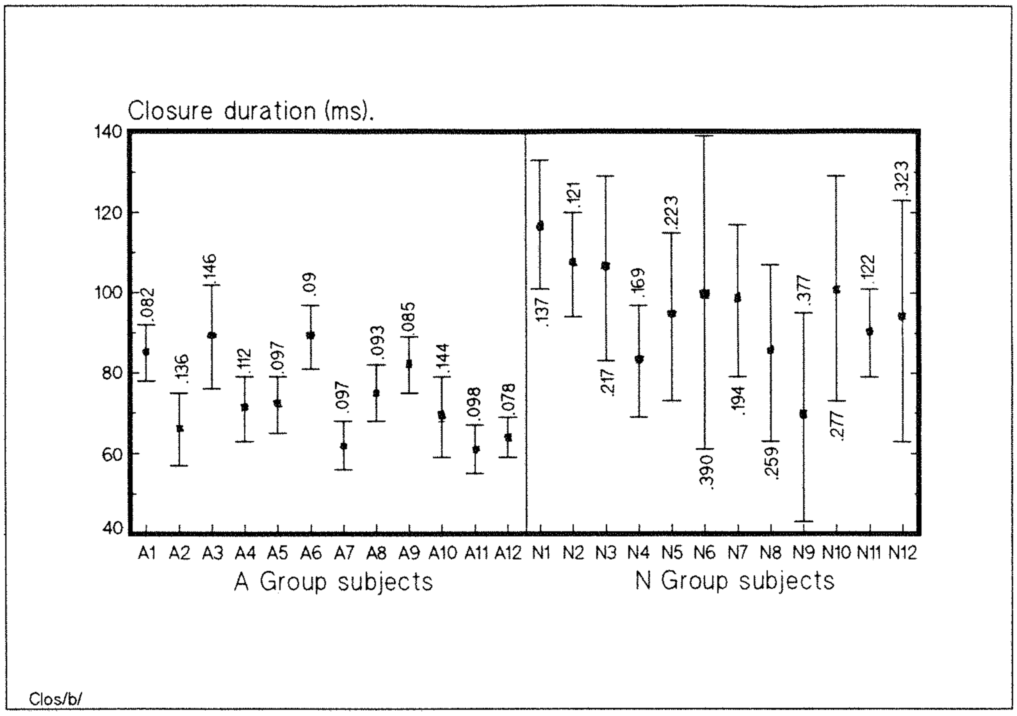

Figure 10. Mean duration and variability of duration of closure for /b/ in the word 'boys' - A & N Group subjects.

3.3.1.3. Mean duration and variability of closure of the initial consonant in the word 'playing'

One adult token (from subject A6) and three N Group tokens (all from subject N11) were excluded because of hesitations affecting this consonant closure duration. A further 13 N Group tokens were excluded because no burst of energy associated with release of closure could be detected on the spectrogram or waveform displays. These were:

2 tokens from subject N1 (/p/ -> [f]),
2 tokens from N6 (/p/ -> [f]),
2 tokens from N8 (/p/ -> [f]),
3 tokens from N9 (/p/ -> [f]),
2 tokens from N10 (/p/ -> [f], [ɸ]),
2 tokens from N12 (/p/ -> [f]).

Figure 11 displays the distribution of all measurable values for the closure duration of the initial consonant in the word 'playing' across all Group A and Group N tokens. The bar-chart shows a wider distribution of values for this consonant closure duration among the N Group tokens than among the adult tokens, with a strong tendency towards longer closure durations in the children's tokens; that is, 42 N Group tokens exhibited durations which were longer than any found in the adult data. There were also two N Group tokens which had shorter durations than any of the adult tokens.

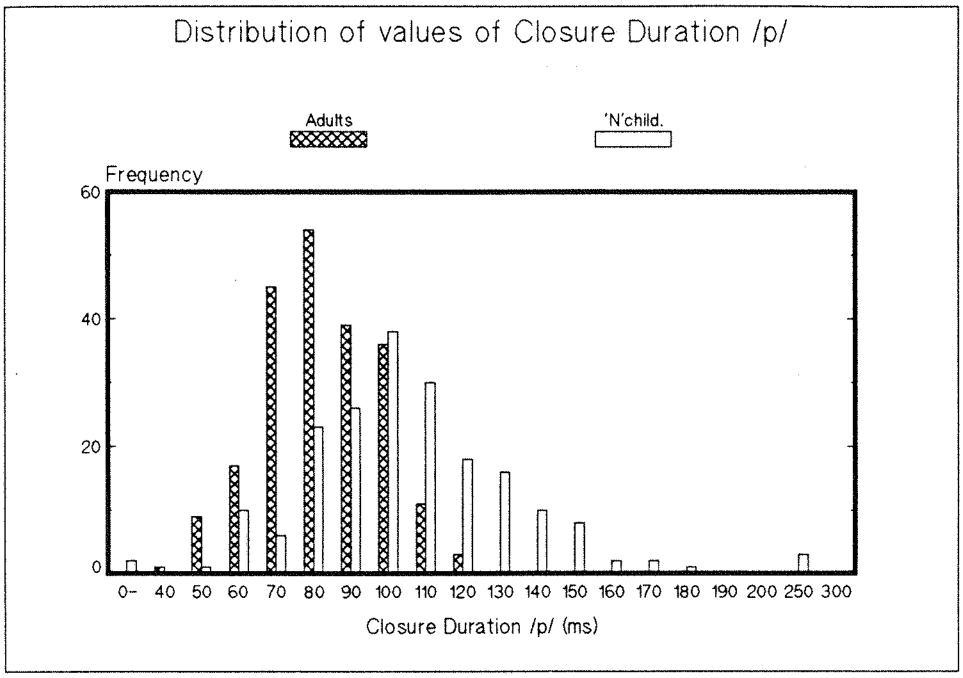

Figure 11. Distribution of closure duration values for /p/ in the word 'playing' - A & N Groups.

Tables 7 & 8 give individual subjects' ranges, means, standard deviations and coefficients of variation for this measure and also group mean values for mean closure duration and coefficient of variation. Referring to these tables it can be seen that in the adult subject group individual mean closure durations for /p/ ranged from 58 - 106 ms with a group mean of 81 ms while the range for the child group was 80 - 130 ms (group mean 105 ms).
Six of the child subjects had mean closure durations for this segment within the adult range and the other six children's values were above the upper end of the adult range. Hence, the group mean value was higher in the child subject group. A t-test showed that this difference between the group means was statistically significant at the 0.1% level ($p = .001$).

The children displayed more individual (intra-subject) variability than the adults (tables 7 & 8 and figure 12, below). The adult values for the coefficient of variation 'C' ranged from 0.051 - 0.171 (group mean 0.106) compared with a child group range of 0.165 -0.338 (group mean 0.248). Only one child fell within the adult range of values for 'C' on this measure, while the other eleven children had values above the upper end of the adult range. A t-test confirmed that the difference between the group mean values for 'C' was statistically significant at the 0.1% level ($p < .001$).

SUBJECT*	**RANGE (ms)**	**MEAN (ms)**	**S.D.(ms)**	**C (SD/M)**
A1	70-110 (40)	93	11	0.118
A2	50-70 (20)	58	7	0.121
A3	95-120 (25)	106	8	0.075
A4	50-80 (30)	67	11	0.164
A5	65-95 (30)	81	7	0.086
A6(17)	90-105 (15)	98	5	0.051
A7	60-90 (30)	74	9	0.122
A8	60-100 (40)	76	13	0.171
A9	60-85 (25)	77	6	0.078
A10	75-100 (25)	89	8	0.090
A11	60-80 (20)	71	6	0.085
A12	60-90 (30)	78	9	0.115

Group mean closure duration = 81 ms
Group mean coefficient of variation = 0.106

* Number of tokens given in brackets if fewer than 18.

Table 7. Duration and variability of duration of closure for /p/ in the word 'playing' - A Group.

SUBJECT*	RANGE (ms)	MEAN (ms)	S.D.(ms)	C (SD/M)
N1(16)	50-185 (135)	107	34	0.318
N2	90-220 (130)	130	39	0.300
N3	55-105 (50)	81	15	0.185
N4	75-130 (55)	103	17	0.165
N5	70-140 (70)	105	20	0.190
N6(16)	65-165 (100)	109	23	0.211
N7	25-145 (125)	96	28	0.291
N8(16)	100-220 (120)	130	29	0.223
N9(15)	20-120 (100)	80	27	0.338
N10(16)	60-150 (90)	95	24	0.253
N11(15)	65-150 (95)	110	21	0.191
N12(16)	60-180 (120)	111	35	0.315

Group mean closure duration = 105 ms
Group mean coefficient of variation = 0.248

* Number of tokens given in brackets if fewer than 18.

Table 8. Duration and variability of duration of closure for /p/ in the word playing - N Group.

Figure 12, below, displays individual means bracketed by standard deviation with coefficients of variation above each bracket; that is, it illustrates the marked difference in intrasubject variability of this consonant closure duration between the adult and child subjects.

In summary, the measures of mean consonant closure duration and variability of closure duration for the initial plosive in the word 'playing' resulted in significant differences between adult and child subjects similar to those found for the other consonant closure measures reported above, that is longer mean durations and higher levels of intra-subject variability were apparent among the young normally developing child speakers compared with the mature adult subjects.

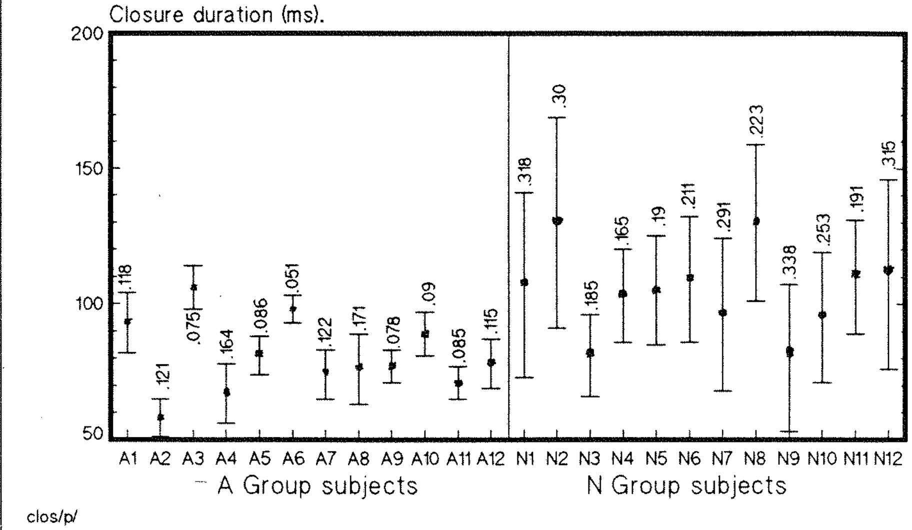

Figure 12. Mean duration and variability of duration of closure for /p/ in the word 'playing' - A & N Group subjects.

3.3.1.4. Mean duration and variability of duration of the vowel in the word 'boys'.

One N Group token (from subject N11) was excluded because a hesitation affected this vowel.

Figure 13 displays the distribution of values of the vowel duration in the word 'boys' across all A Group and N Group tokens. The bar-chart shows a greater spread of values for this vowel duration in the child data than among tokens from adult subjects; two N Group tokens were found to have durations shorter than any found in the adult data, and 18 N Group tokens exhibited durations longer than in any of the adult tokens. The bar-chart also shows a tendency for the child speakers to produce the vowel with durations in the lower half of the adult range of values.

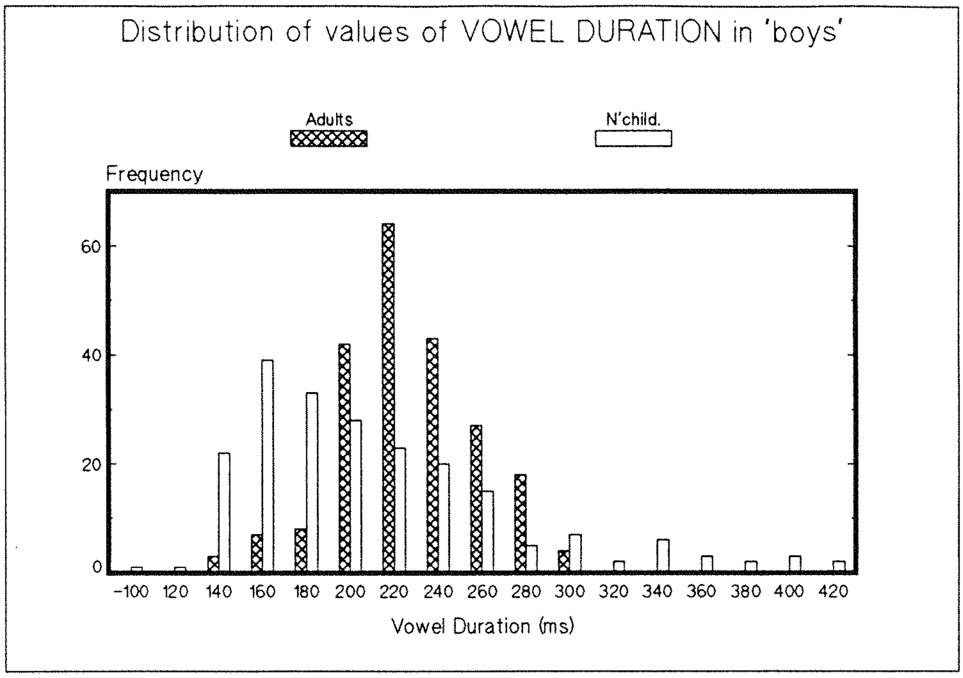

Figure 13. Distribution of durational values for the vowel in the word 'boys' - A & N Groups.

Tables 9 & 10 show individual subjects' ranges, means, standard deviations and coefficients of variation on this measure and also group mean values for mean vowel duration and coefficient of variation. Referring to these tables it can be seen that the range of mean vowel durations for the adults was 165 - 264 ms with a group mean of 220 ms, and the range among the child subjects was 144 - 336 ms with a group mean of 205 ms. Eight child subjects fell within the adult range for mean vowel duration, while three had mean vowel durations below the lower extreme of the adult range and one child had a mean value which was higher than any of the adults. A t-test was applied which showed that the difference between the group means was not statistically significant ($p > .05$).

Child subjects exhibited more individual (intra-subject) variability than the adult subjects on this measure of vowel duration (tables 9 & 10 and figure 14 below). The values of 'C' among adult subjects for the vowel duration measure ranged from 0.048 - 0.158 (group mean 0.074) and from 0.125 - 0.238 (group mean 0.164) in the normally-developing child group. Six child subjects had values for 'C' which fell within the adult range and the remaining six children's values were above the upper limit of the adult range. A t-test confirmed that the difference between the group means for values of 'C' was statistically significant at the 0.1% level ($p < .001$).

Referring again to table 9, it can be seen that one of the adult subjects (subject A7) exhibited much shorter and more variable vowel durations than any of the other adult subjects and, in fact, displayed greater variability on this measure than did half of the child subjects. This adult subject exhibited the shortest mean phrase duration found in the adult group, that is, he was the fastest adult speaker.

SUBJECT	RANGE (ms)	MEAN (ms)	S.D.(ms)	C (SD/M)
A1	170-225 (55)	203	17	0.084
A2	195-230 (35)	210	10	0.048
A3	195-240 (45)	212	10	0.047
A4	175-260 (85)	211	19	0.090
A5	230-285 (55)	254	14	0.055
A6	185-240 (55)	204	15	0.074
A7	135-220 (85)	165	26	0.158
A8	210-275 (65)	239	18	0.075
A9	220-285 (65)	253	20	0.079
A10	205-260 (55)	229	14	0.061
A11	180-230 (50)	198	12	0.061
A12	240-295 (55)	264	16	0.061

Group mean vowel duration = 220 ms
Group mean coefficient of variation = 0.074

Table 9. Duration and variability of duration of the vowel in the word 'boys' - A Group.

SUBJECT*	RANGE (ms)	MEAN (ms)	S.D.(ms)	C (SD/M)
N1	160-340 (180)	247	52	0.211
N2	205-340 (135)	256	32	0.125
N3	190-420 (230)	336	60	0.179
N4	130-240 (110)	159	26	0.163
N5	155-280 (125)	207	35	0.169
N6	130-350 (220)	210	50	0.238
N7	150-255 (105)	197	29	0.147
N8	100-170 (70)	144	19	0.132
N9	130-220 (90)	170	23	0.135
N10	125-210 (85)	159	22	0.138
N11(17)	170-250 (80)	200	25	0.125
N12	105-260 (155)	171	36	0.211

Group mean vowel duration = 205ms

Group mean coefficient of variation = 0·164

* Number of tokens given in brackets if fewer than 18.

Table 10. Duration and variability of duration of the vowel in the word 'boys' - N Group.

Figure 14, below, displays individual means bracketed by standard deviation with coefficients of variation above each bracket, that is, it illustrates the marked difference in intra-subject variability of this vowel duration between adult and child subjects.

In summary the measures of mean duration and variability for the vowel in the word 'boys' showed a significantly higher level of intra-subject variability in the child group compared with the adult group, which is consistent with the other measures of intra-subject temporal variability reported so far. There was also a wider spread of values for mean duration in the N Group compared with the A Group (greater inter-subject variability of mean duration). However, on this segmental measure there was no statistically significant difference of mean duration between the two subject groups and, in fact, contrary to the results of the other segmental measures, the child subjects exhibited a tendency towards shorter vowel durations.

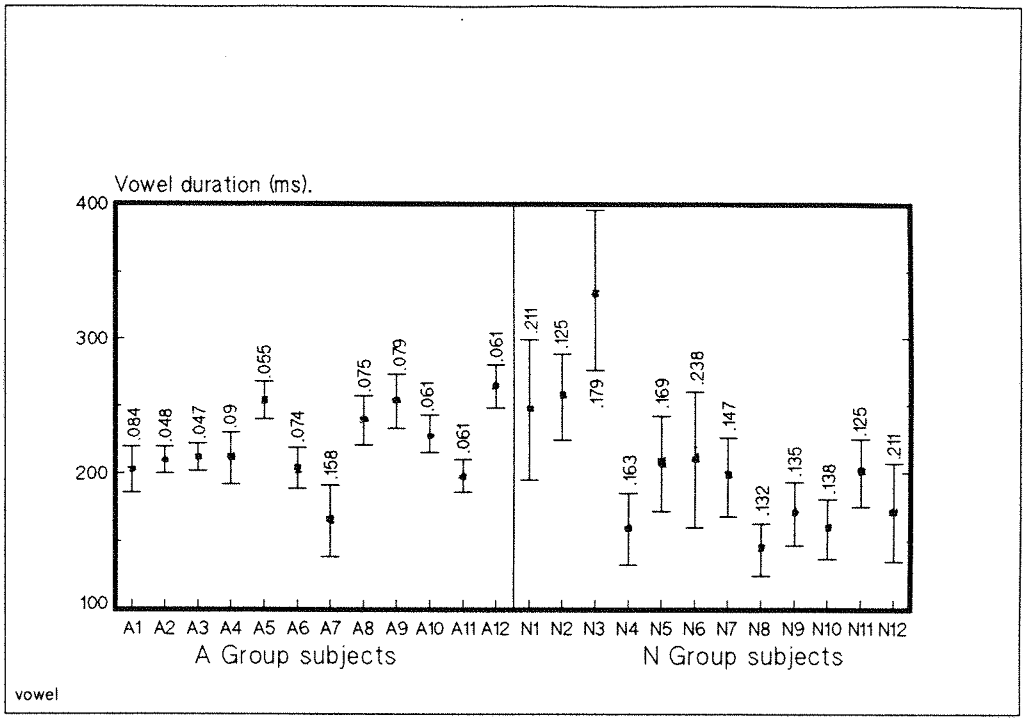

Figure 14. Mean duration and variability of duration of the vowel in the word 'boys' - A & N Group subjects.

3.3.1.5. Mean duration and variability of voice onset (VOT) for the initial consonant in the word 'two'.

Six N Group tokens were excluded from this measure. These were:
1 token from subject N3 in which there was noise at the beginning of the recording which made measurement of the onset of voicing for the following vowel unreliable;2 tokens from subject N10 and 1 from subject N12 in which the word 'two' was spoken in whisper;1 token from subject N10 in which the word 'two' was omitted, and 1 token from this same subject in which the target stop consonant /t/ was affricated ([ts]).
Figure 15 displays values for this voice onset time for all measureable tokens from A Group and N Group subjects. The bar-chart shows that the range of values for this VOT was greater among the N Group tokens than among the adult tokens, with 12 tokens from child subjects exhibiting VOTs below the adult range and 7 children's tokens exhibiting VOTs above the adult range.

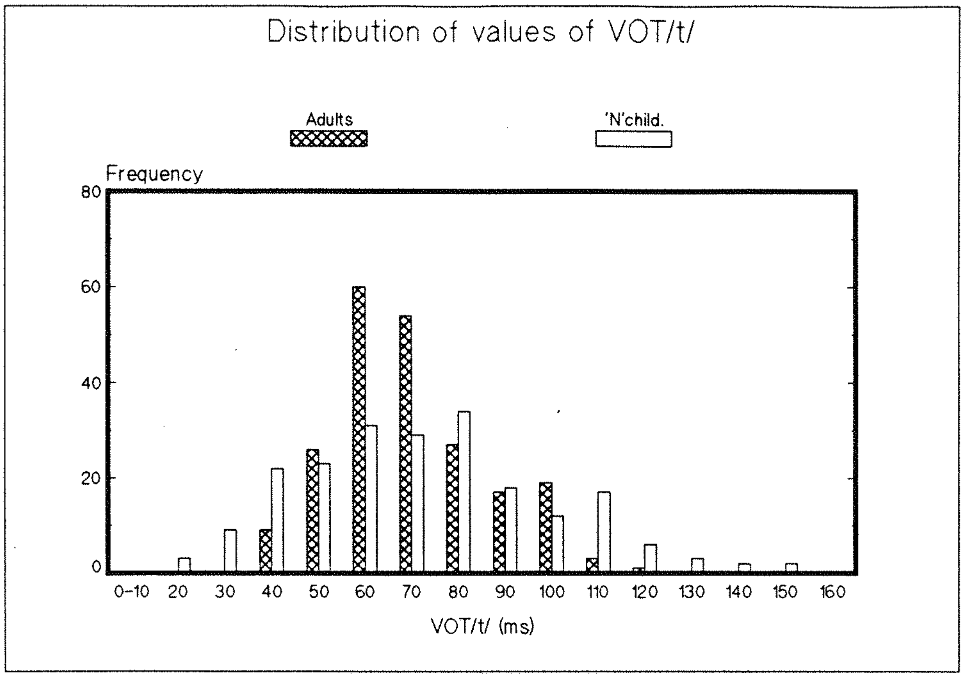

Figure 15. Distribution of values for the VOT of /t/ in the word 'two' - A & N Groups

Tables 11 & 12 show individual subjects' ranges, means, standard deviations and coefficients of variation for this measure, as well as group mean values for mean VOT and coefficient of variation. These tables show that the range of mean durations for this voice onset measure was very similar in the adult and normally-developing child subject groups. Mean VOTs for /t/ ranged from 44 - 98 ms (group mean 68 ms) in the adult group and the range for the child subjects was 42 - 98 ms with a group mean of 70 ms. Eleven of the child subjects' mean values fell within the adult range and only one child subject fell below the adult range. A t-test confirmed that there was no statistically significant difference between the group means.
There was, however, a marked difference between child and adult subjects in terms of individual (intra-subject) variability, (tables 11 & 12 and figure 16, below). The range of values for 'C' among adult subjects was 0.082 - 0.147 (group mean 0.117) and for the children 0.183 - 0.452 (group mean 0.31); that is, all the child subjects had coefficients of variation which were above the upper limit of the adult range. A t-test confirmed that the difference between the group means for values of 'C' was statistically significant at the 0.1% level ($p < .001$).

SUBJECT	RANGE (ms)	MEAN (ms)	S.D.(ms)	C (M/SD)
A1	80-115 (35)	98	8	0.082
A2	50-80 (30)	63	8	0.127
A3	45-70 (25)	58	6	0.103
A4	60-100 (40)	77	11	0.143
A5	50-70 (20)	61	6	0.098
A6	50-70 (20)	61	6	0.098
A7	50-85 (35)	69	10	0.145
A8	60-90 (30)	75	11	0.147
A9	55-80 (25)	69	8	0.116
A10	50-70 (20)	57	6	0.105
A11	35-55 (20)	44	6	0.136
A12	70-105 (35)	89	10	0.112

Group mean voice onset time = 68 ms

Group mean coefficient of variation = 0.118

Table 11. Duration and variability of VOT for /t/ in the word 'two' - A Group subjects.

SUBJECT*	RANGE (ms)	MEAN (ms)	S.D.(ms)	C (M/SD)
N1	40-130 (90)	73	25	0.342
N2	50-100 (50)	67	15	0.224
N3(17)	50-140 (90)	98	22	0.224
N4	30-100 (70)	63	21	0.333
N5	20 -110 (90)	42	19	0.452
N6	30-120 (90)	57	23	0.404
N7	55-110 (55)	82	15	0.183
N8	20-110 (90)	65	26	0.400
N9	20-85 (65)	61	19	0.311
N10(10)	55-120 (65)	82	19	0.232
N11	55-130 (75)	94	29	0.309
N12(17)	40-80 (40)	56	17	0.304

Group mean voice onset time = 70ms
Group mean coefficient of variation = 0.31
* Number of tokens given in brackets if fewer than 18.

Table 12. Duration and variability of VOT for /t/ in the word 'two' - N Group subjects.

Figure 16, below, displays individual means bracketed by standard deviations with coefficients of variation given above each bracket; that is, it illustrates the much higher levels of intra-subject variability on this VOT measure found in the child data compared with the adult data.

In summary, the results of the measurements of VOT in the initial plosive of the experimental phrase have shown significantly higher intra-subject variability in the child speakers compared with the adult speakers which is consistent with all the measures reported so far, but no statistically significant difference in mean VOTs was found between child and adult subjects.

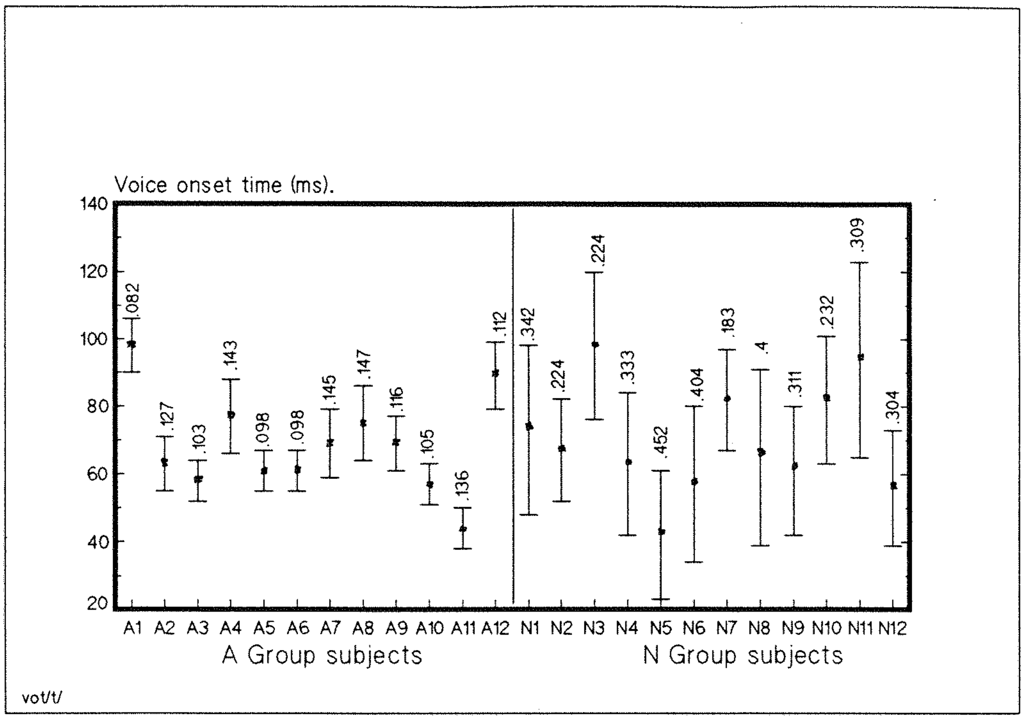

Figure 16. Mean duration and variability of VOT for /t/ in the word 'two' - A & N Group subjects.

3.3.1.6. Mean duration and variability of duration of voice onset (VOT) for the initial consonant in the word 'boys'.

One adult token from subject A7 was excluded because the target stop consonant was realised as a bilabial nasal [m].
26 N Group tokens were excluded; reasons were given in section 3.3.1.2., above.

Figure 17 displays the values of the VOT in the initial consonant in the word 'boys' across all measureable tokens in the adult and N Group data.The figure shows that the majority of measurable N Group tokens of /b/ were found to exhibit VOTs similar to those found in the adult data but there was a greater range of values in the child data than in the adult data, with 16 N Group tokens having VOTs above the adult range of values. (It will be seen in the subsequent analysis of the phonological form of the data, in section 4 of this chapter, that many of the N Group subjects' realisations of this segment which showed VOTs above about 45 ms were perceived as voiceless.)

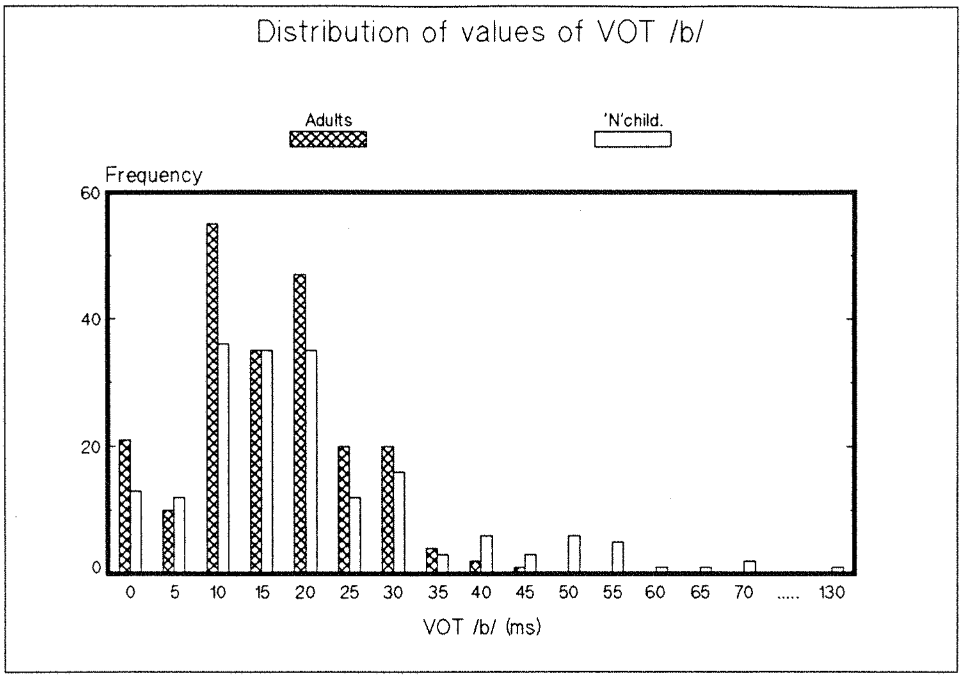

Figure 17. Distribution of VOT values for /b/ in the word 'boys' - A & N Groups

Tables 13 & 14 give individual subjects' ranges, means, standard deviations and coefficients of variation for this measure, as well as group mean values for mean duration and variability. It can be seen that the range of VOTs among adult subjects' for this plosive consonant was 3 - 26 ms with a group mean value of 16 ms and the range in the normally developing child subject group was 7 - 44 ms with a group mean value of 21 ms. Nine of the child subjects were found to have mean VOTs for /b/ which were within the adult range of mean values, while the remaining three child subjects had mean VOTs above the adult range. A t-test showed that the difference between the group means on this measure was not statistically significant ($p > .05$).

The evaluation of individual variability for this VOT measure proved to be problematical: using the criteria of measurement described above (section 3. 2.3.). Many tokens from subjects in both groups exhibited VOTs of 0 ms which resulted in very low values for individual mean duration of VOT. Since the coefficient of variation measure (C) is derived from the Standard Deviation / Mean, very low values for Mean duration result in very high values for 'C', even when standard deviation is small. The values obtained for 'C' are reported in tables 13 and 14 in the usual way, but since they do not yield a meaningful measure of individual variability in this particular instance, individual variability of VOT for this plosive consonant is evaluated and compared between subject groups using individual standard deviations.

Adult subjects exhibited standard deviations on this VOT measure ranging from 4 - 9 ms with a group mean value of 6 ms. The range in the normally-developing child group was 4 - 24 ms with a group mean value of 12 ms. A t-test indicated that the difference between the group means for individual standard deviation was statistically significant (p = .01).

SUBJECT*	**RANGE (ms)**	**MEAN (ms)**	**S.D.(ms)**	**C (SD/M)**
A1	10-30 (20)	20	6	0.3
A2	10-40 (30)	22	6	0.273
A3	0-15 (15)	8	4	0.5
A4	0-15 (15)	9	5	0.556
A5	5-20 (15)	13	5	0.385
A6	0-15 (15)	3	5	1.667
A7(17)	10-40 (30)	26	6	0.231
A8	10-45 (35)	23	8	0.348
A9	10-30 (20)	18	6	0.333
A10	0-30 (30)	11	8	0.727
A11	10-20 (10)	15	4	0.267
A12	0-35 (35)	24	9	0.375

Group mean voice onset time = 16ms
Group mean standard deviation = 6 ms (see text)

* Number of tokens given in brackets if fewer than 18.

Table 13. Duration and variability of VOT for /b/ in the word 'boys' - A Group.

SUBJECT*	RANGE (ms)	MEAN (ms)	S.D.(ms)	C (SD/M)
N1	15-130 (115)	44	24	0.545
N2	0-25 (25)	14	6	0.429
N3(17)	0-15 (15)	7	4	0.667
N4	10-40 (30)	19	9	0.474
N5(16)	0-40 (40)	18	12	0.667
N6(16)	0-45 (45)	14	13	0.929
N7	10-50 (40)	22	9	0.409
N8(12)	0-65 (65)	31	19	0.613
N9(10)	5-30 (25)	15	8	0.533
N10(17)	10-70 (60)	32	21	0.656
N11	5-25 (20)	14	6	0.429
N12(12)	0-50 (50)	20	13	0.65

Group mean voice onset time = 21 ms
Group mean standard deviation = 12 ms (see text)

* Number of tokens given in brackets if fewer than 18.

Table 14. Duration and variability of VOT for /b/ in the word 'boys' - N Group

Figure 18, below, displays individual means bracketed by standard deviations; that is it illustrates the marked differences in intra-subject variability on this VOT measure between the adult and child groups.

In summary, the measurement of VOT in the initial plosive in the word 'boys' has shown significantly higher levels of intra-subject variability in the child subjects in common with all the variability measures reported so far, but no significant difference of mean duration of VOT between the two subject groups.

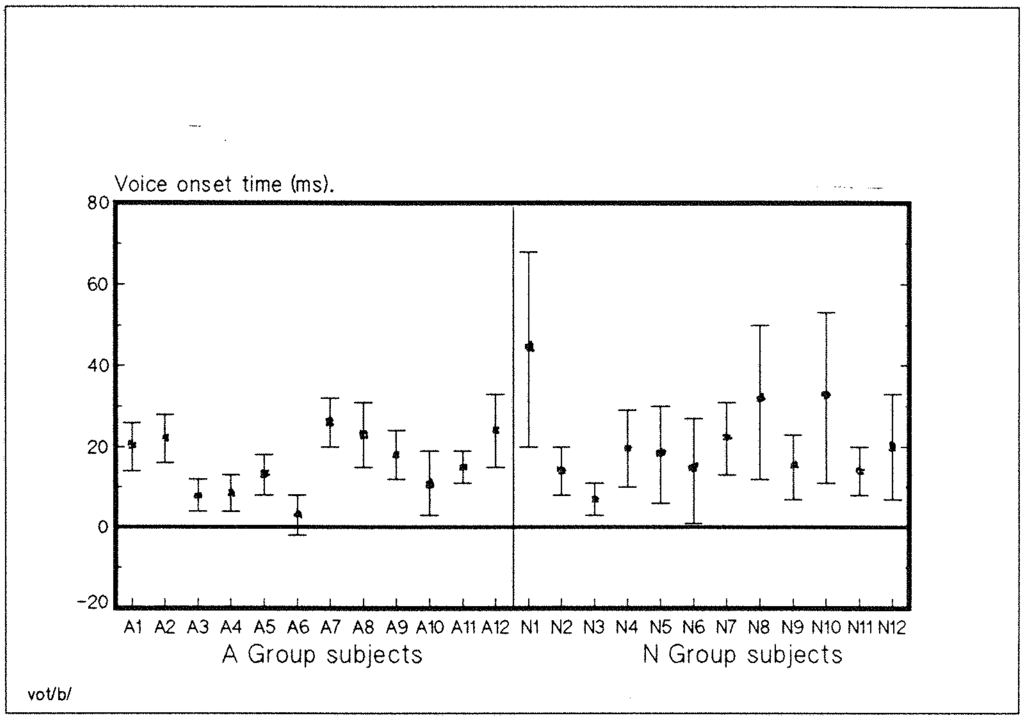

Figure 18. Mean duration and variability of VOT for /b/ in the word 'boys' - A & N Group subjects.

3.3.1.7. Mean duration and variability of voice onset (VOT) for the initial consonant in the word 'playing'.

One adult token (from subject A6) and one child token (from subject N11) were excluded because of hesitations affecting this segment. A further 13 N Group tokens were excluded; reasons were given in section 3.3.1.3. above.

Figure 19 displays the distribution of values of the VOT for this plosive consonant across all measurable tokens in the adult and normal child data. This bar-chart shows a wider range of VOT values among the child group tokens than among the adult tokens, with a tendency for child subjects to exhibit long VOTs compared with adult speakers. That is, the N Group data included 41 tokens in which the VOT was longer than in any of the adult tokens while only 4 tokens from child subjects exhibited VOTs which were shorter than any in the adult data.

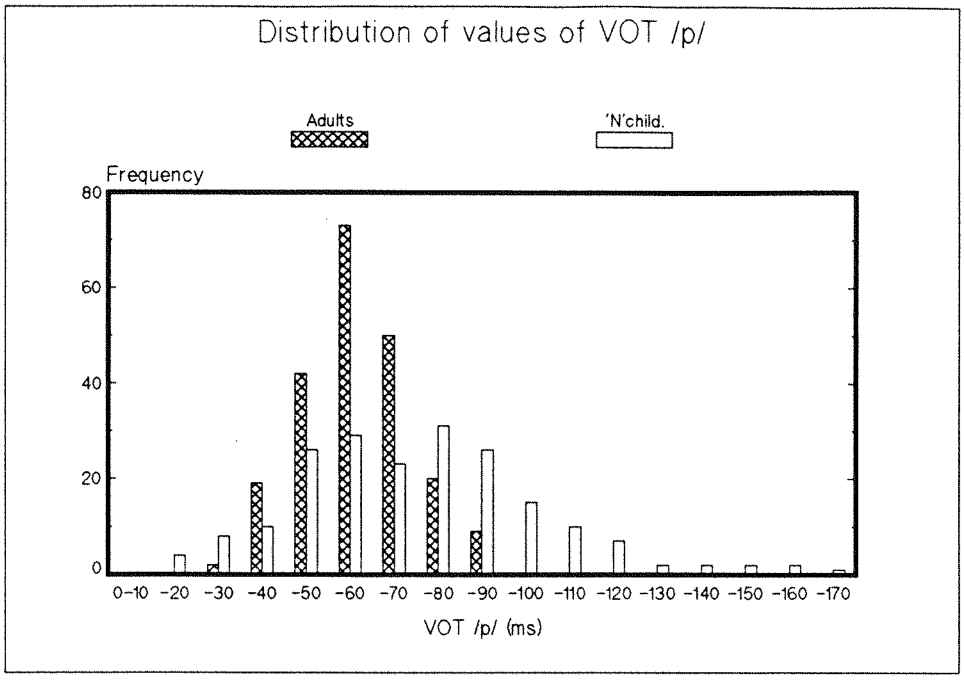

Figure 19. Distribution of VOT values for /p/ in the word 'playing' - A & N Groups

Tables 15 & 16 show individual subjects' ranges, means, standard deviations and coefficients of variation for this measure as well as group mean values for mean VOT and for variability. The tables show that adult subjects exhibited individual mean VOTs for /p/ in the word 'playing' which ranged from 44 - 73 ms with a group mean value of 60 ms and in the normally-developing child subject group the range was 47-98 ms (group mean value 74 ms). Seven of the child subjects were found to have mean VOTs which were within the range of adult mean values, while the remaining five child subjects' values were above the adult range.
A t-test demonstrated that the difference between the group means for this VOT measure was of only marginal statistical significance: $p > .01$ (value to 3 decimal places = .017).

The child subjects exhibited higher levels of intra-subject variability on this VOT measure than the adult speakers. The ranges of individual values for coefficient of variation were 0.086 - 0.204 (group mean 0.152) in the adult group and 0.165 - 0.494 (group mean 0.316) in the child group. One N Group subject was found to have a coefficient of variation for this VOT measure which was within the adult range of values, while the remaining eleven normally-developing child subjects exhibited levels of individual variability above the adult range.

A t-test confirmed that the difference between the group means on this measure of variabilty was statistically significant at the .1% level ($p < .001$).

SUBJECT*	RANGE (mS)	MEAN (mS)	S.D.(mS)	C (SD/M)
A1	60-90 (30)	70	8	0.114
A2	55-90 (35)	73	11	0.151
A3	50-70 (20)	58	5	0.086
A4	30-70 (40)	54	11	0.204
A5	30-65 (35)	49	10	0.204
A6(17)	40-55 (15)	44	5	0.114
A7	40-70 (30)	54	10	0.185
A8	55-85 (30)	69	8	0.116
A9	50-75 (25)	61	7	0.115
A10	40-70 (30)	57	8	0.14
A11	40-80 (40)	60	12	0.2
A12	50-90 (40)	68	13	0.191

Group mean voice onset time = 60 ms
Group mean coefficient of variation = 0.152

* Number of tokens given in brackets if fewer than 18.

Table 15. Duration and variability of VOT for /p/ in the word 'playing' - A Group subjects.

SUBJECT*	RANGE (mS)	MEAN (mS)	S.D.(mS)	C (SD/M)
N1(16)	40-170 (130)	91	34	0.374
N2	50-125 (75)	73	20	0.274
N3	40-90 (50)	58	13	0.224
N4	60-120 (60)	91	15	0.165
N5	20-95 (75)	47	21	0.447
N6(16)	30-80 (50)	56	14	0.25
N7	45-155 (110)	87	27	0.31
N8(16)	30-160 (130)	77	38	0.494
N9(15)	20-125 (105)	66	25	0.379
N10(16)	30-115 (85)	67	23	0.343
N11(15)	60-135 (75)	98	21	0.214
N12(16)	30-115 (85)	72	23	0.319

Group mean voice onset time = 74 ms
Group mean coefficient of variation = 0.316

* Number of tokens given in brackets if fewer than 18.

Table 16. Duration and variability of VOT for /p/ in the word 'playing' - N Group subjects.

Figure 20, below, displays individual mean values bracketed by standard deviations with coefficients of variation above the brackets; that is, it illustrates the marked difference in intra-subject variability on this VOT measure between the adult and child subject groups.

In summary, the measurement of VOT in the the initial plosive in the word 'playing' has shown significantly higher levels of intra-subject variability in the child subjects, in common with all the other variability measures reported so far, but the difference between the groups on the measure of mean duration was of only marginal statistical significance.

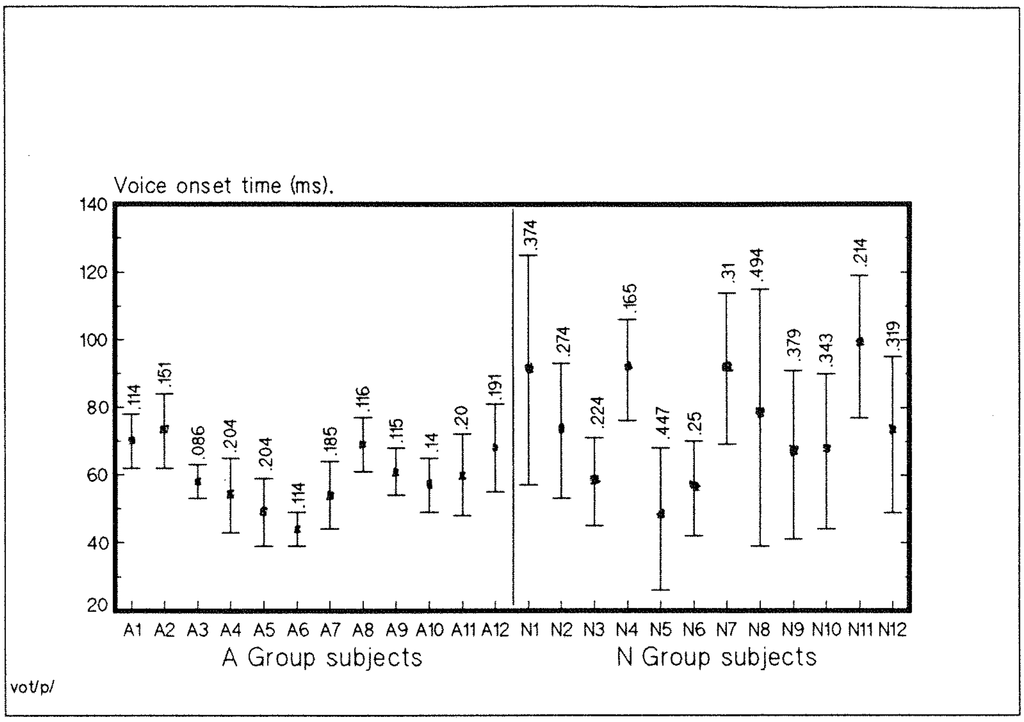

Figure 20. Mean duration and variability of VOT for /p/ in the word 'playing' - A & N Group subjects.

3.3.2. Further analysis of phrase and segment duration measures.

Several additional analyses were performed on the temporal acoustic measurements reported above, in order to explore further the relationships among the various measures. This section reports the results of these additional analyses.

3.3.2.1. Relationship between mean phrase duration and mean segment duration measures.

As reported above, the child subject group was found to have significantly longer mean phrase durations than the adult group ($p < .01$). Among the segmental measurements the two consonant closure durations showed the most significantly longer mean values in the child data compared with the adult data ($p < .001$); the difference between the two groups on VOT for the plosive /p/ in the word 'playing' reached marginal significance ($p = .017$) while differences of mean duration between the two groups did not reach statistical significance for the remaining segmental measures. These results suggest that, among the segmental durations measured, mean durations of consonant closures are the most significant in determining overall mean phrase duration. To explore these relationships further, Pearson Coefficients of Correlation were derived (across all subjects) to test the strength of the relationship between subjects' mean phrase duration and their mean duration on each segmental measure. The values of the Pearson Correlation Coefficient 'r' are reported in table 17 where it can be seen that positive correlations were found between mean phrase duration and each of the mean segmental duration measures, but only those correlations involving the two closure duration measures were statistically significant.

It might be expected, intuitively, that correlation between segmental duration and phrase duration depends directly upon the relative length of a segment, that is, that longer segments will have the greatest significance in determining overall phrase duration. However, the vowel segment (in the word 'boys') has the longest mean duration of all the segments measured and, as can be seen in table 17 correlation with mean phrase duration is lower for this vowel segment than for the two consonant closure durations.

It should, of course, be borne in mind that only selected segment durations have been measured in this experiment, and it is possible that other segment durations which have not been measured may have equally significant or more significant correlations with mean phrase duration.

SEGMENT	VALUE OF 'r'	SIGNIFICANCE
Closure duration of initial plosive in the word 'boys'	r = .68	0.1% level
Closure duration of initial plosive in the word 'playing'	r = .59	1% level
Vowel duration in the word 'boys'	r = .44	not statistically significant
VOT of initial plosive in the word 'two'	r = .23	not statistically significant
VOT of initial plosive in the word 'boys'	r = .07	not statistically significant
VOT of initial plosive in the word 'playing'	r = .37	not statistically significant

Table 17. Correlations between mean segment durations and mean phrase duration - pooled A & N Group data.

3.3.2.2. Comparison of temporal variability in child and adult subjects who exhibited similar mean phrase durations.

Results reported above have demonstrated significantly longer phrase durations among child subjects than among the adult speakers, and also significantly higher levels of temporal variability among child subjects. In Chapter Two it was emphasised that several previous investigations have considered the possibility that differences in temporal variability between adult and child subjects are a direct consequence of the longer durations found in child data; that is, that the higher levels of variability reported in child data are statistical artefacts rather than a consequence of differences in maturity of speech motor control.

To explore this possibility with respect to the present data child and adult subjects who exhibited similar mean phrase durations were compared on measures of individual temporal variability. Five of the normal child subjects were found to exhibit mean phrase durations within the adult range of values (see section 3.3.1.1.).

Table 18, below, shows that when each of these five child subjects is compared with an adult speaker exhibiting similar mean phrase duration it is found that the child subjects are considerably more variable, and therefore this high variability cannot be attributed to absolute durational values. That is, although these five children achieved adult-like mean phrase durations they were, in general, much less able than the adult speakers to exercise consistent temporal control over their speech production.

Examining table 18, it can be seen that there were some exceptions to this general finding:
(i) subject A7 exhibited greater variability than the child subject with whom he is compared on the measure of variability of vowel duration. This adult subject has already been identified as exhibiting exceptionally short and variable vowel durations;
(ii) subject N4 exhibited considerably lower levels of temporal variability than any of the other child subjects included in table 18. In fact, on one measure of variability, closure duration for the initial plosive in the word 'playing', subject N4 exhibited a lower level of variability than the adult speaker.

SUBJ.	MEAN PHRS. DURN. (ms)	'C' PHRS. DURN.	'C' CLOS. /b/	'C' CLOS. /p/	'C' VOWEL DURN.	'C' VOT /t/	S.D. VOT /b/ (ms)	'C' VOT /p/
N9	1113	.222	.377	.338	.135	.311	8	.379
A7	1106	.061	.097	.122	.158	.145	6	.185
N10	1225	.148	.277	.253	.138	.232	21	.343
A11	1229	.034	.098	.085	.061	.136	4	.2
N4	1426	.096	.169	.165	.163	.333	9	.165
A8	1428	.053	.093	.171	.075	.147	8	.116
N12	1453	.147	.323	.315	.211	.304	13	.319
A9	1444	.031	.085	.078	.079	.116	6	.115
N8	1525	.079	.259	.223	.132	.4	19	.494
A12	1529	.031	.078	.115	.061	.112	9	.191

Table 18. Comparison of temporal variability in five N Group and five A Group subjects matched for mean phrase duration.

3.3.2.3. Relationships between measures of mean duration and measures of temporal variablity.

This sub-section explores relationships between absolute duration and variability of duration for each of the temporal acoustic measurements to determine the nature of those relationships and whether they are similar in the child and adult data. Pearson correlation coefficients 'r' are derived where appropriate, to test the strength of relationships. Correlations derived from such small samples must, of course, be interpreted with caution, and are regarded here only as additional confirmation of relationships suggested by visual inspection of scatterplots.
The data is also analysed to determine whether any relationship is apparent between individual subjects' overall speed of utterance (mean phrase duration) and overall temporal variability across all measures.

Figures 21 -27, on the following pages, plot individual mean duration against individual temporal variability for each of the phrase and segment measures.

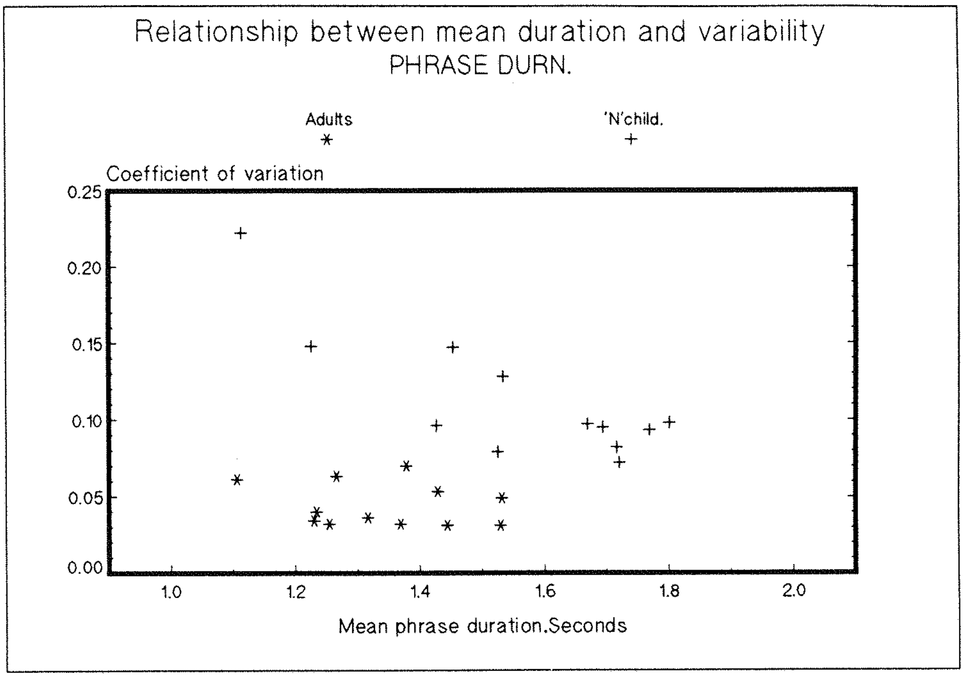

Figure 21. Scatterplot of the relationship between mean duration and variability of the experimental phrase - A & N Groups.

It can be seen in figure 21 that the distribution of points for the adult subjects does not suggest any linear relationship between the measures of mean phrase duration and variability of phrase duration. For the child subjects, however, the distribution suggests a degree of negative correlation; that is, a relationship in which short mean phrase durations tend to be associated with high degrees of durational variability. The strength of this relationship was tested by deriving a Pearson Correlation Coefficient 'r'. The value of 'r' was found to be -.83 which is statistically significant at the .01 level.

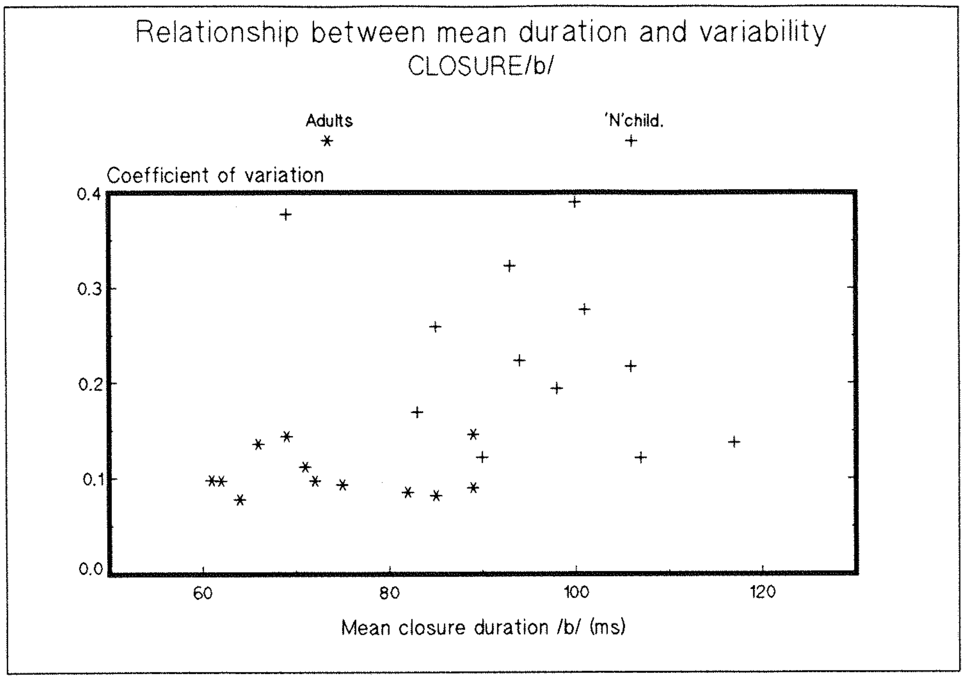

Figure 22. Scatterplot of the relationship between mean and variability of closure duration for /b/ in the word 'boys' - A & N Groups.

Visual inspection of the scatterplot shown in figure 22 suggests an overall positive correlation between mean closure duration and variability of closure duration of the initial plosive in the word 'boys' across the two subject groups which can be regarded as a consequence of the marked differences between the two groups; that is, adult subjects exhibited relatively short closure durations and relatively low levels of variability whereas child subjects displayed relatively long closure durations and relatively high levels of variability. However, when the distribution of scatterplot points within each subject group are considered separately, no linear relationship between mean closure duration and variability of closure duration is in evidence. When Pearson Correlation Coefficients are derived the values of 'r' are -.57 for the adult subject group and -.42 for the child subject group. Neither of these values of 'r' reach significance at the .01 level.

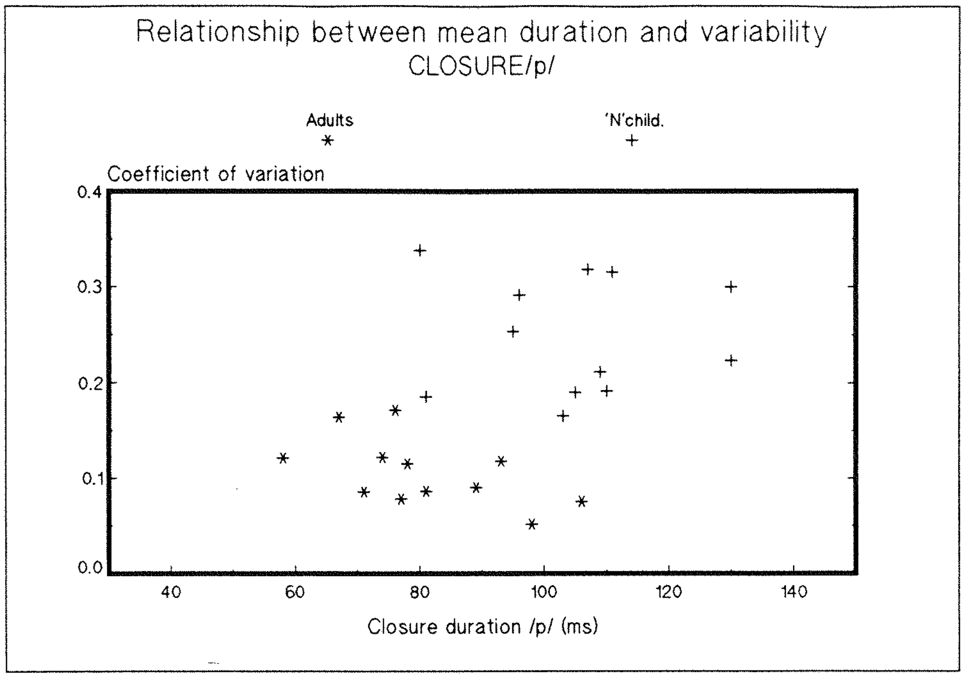

Figure 23. Scatterplot of the relationship between mean and variability of closure duration for /p/ in the word 'playing' - A & N Groups

The distribution of points on the scatterplot in figure 24 suggests some degree of overall positive correlation across all subjects between mean closure duration and variability for the initial plosive in the word 'playing'. This reflects the finding, reported above, that relatively short and invariant closure durations were found in the adult data and relatively long and variable durations in the child data. However, when the distribution of points within each subject group are considered separately, no correlation between mean duration and variability is apparent. Small, statistically insignificant values for the Pearson Coefficient of Correlation 'r' (-.01 for the adult data and -.04 for the child data) confirm these observations.

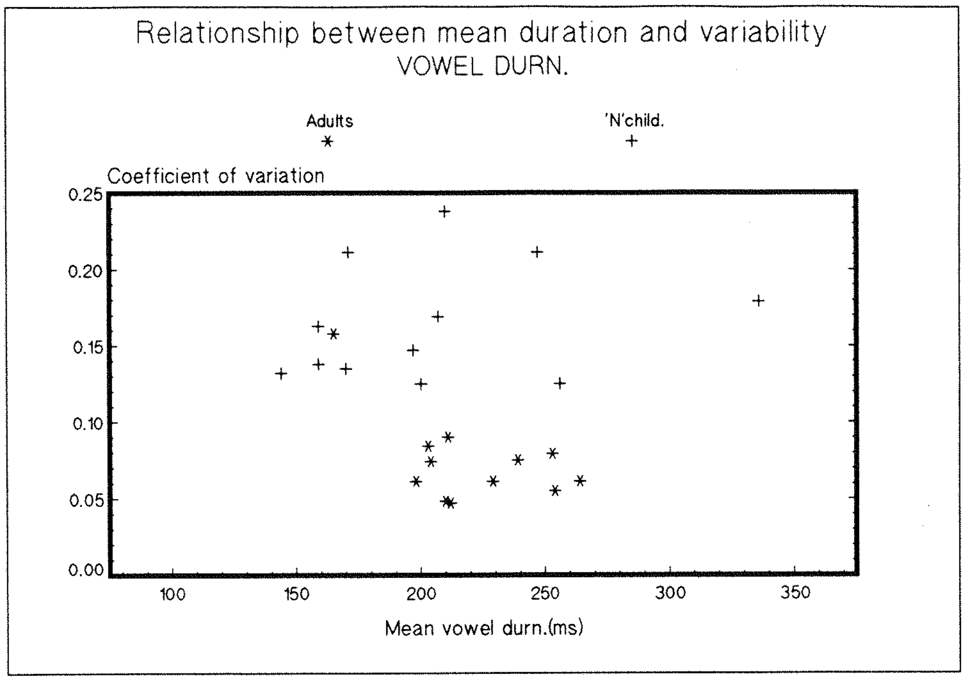

Figure 24. Scatterplot of the relationship between mean and variability of duration for the vowel in the word 'boys' - A & N Groups.

The scatterplot shown in figure 24 does not suggest any significant degree of correlation between mean vowel duration and variability of vowel duration when all subjects' points are considered together. If the points on the scatterplot relating to each of the subject groups are examined separately there is no evidence for a linear relationship between the two measures within the child subject group. The value of 'r' was found to be .22 which is not statistically significant. The points relating to adult subjects form a fairly tight but randomly distributed cluster with the exception of one adult subject, A7, whose short and variable vowel durations have been noted above. When a Pearson Correlation Coefficient is derived for the adult data the value of 'r' is found to be -.74 which is significant at the .01 level, but this apparently strong negative correlation depends heavily upon this one subject's measures and does not reflect a general trend in the adult data.

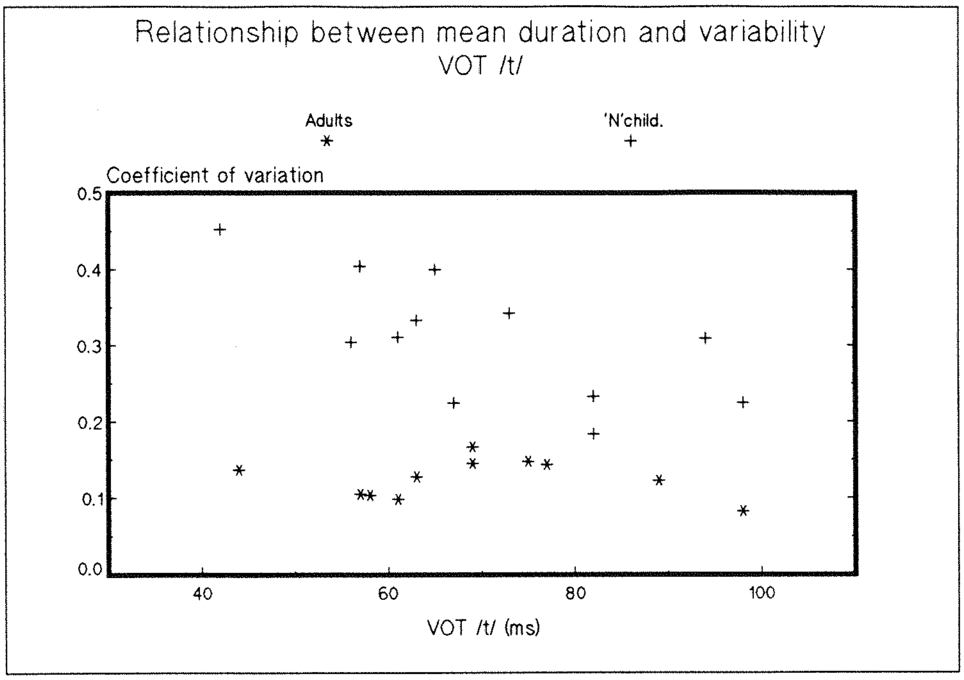

Figure 25. Scatterplot of the relationship between mean duration and variability of VOT for /t/ in the word 'two' - A & N Groups.

The distribution of points shown on the scatterplot in figure 25 relating to the adult subjects' data does not suggest any linear relationship between the measures of mean VOT and variability of VOT in the initial plosive in the word 'two'. However, the points relating to the child group data suggests that a negative relationship may exist between mean duration and variability of duration for this measure; that is, a relationship in which short mean VOTs tend to be associated with relatively high levels of temporal variability. A Pearson Correlation Coefficient 'r' was derived to test the strength of this apparent relationship and the value of 'r' was found to be -.69 which is significant at the .01 level.

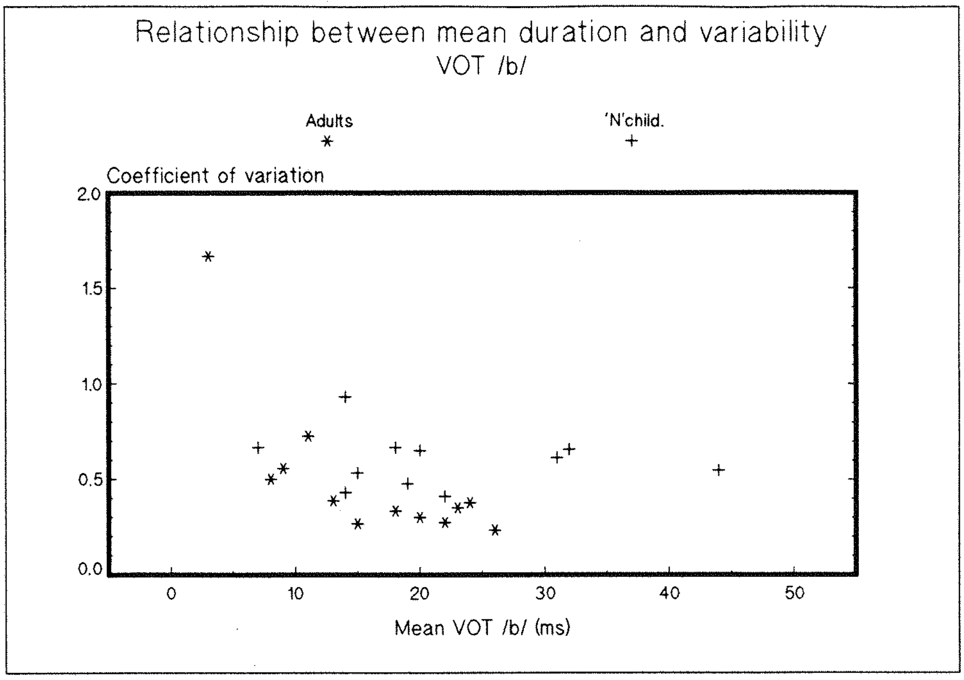

Figure 26. Scatterplot of the relationship between mean duration and variability of VOT for /b/ in the word 'boys' - A & N Groups.

The scatterplot shown in figure 26 plots individual mean VOT for the initial plosive /b/ in the word 'boys' against individual coefficient of variation for that measure.This plot is included for the sake of completeness, but is of limited value, since, as discussed in section 3.3.1.6. above, the measure of coefficient of variation (standard deviation/mean) did not yield a meaningful measure of individual variability in this particular instance.No correlation measures were performed on this measure, but visual inspection of the scatterplot point suggests some overall negative correlation between mean VOT and variability.

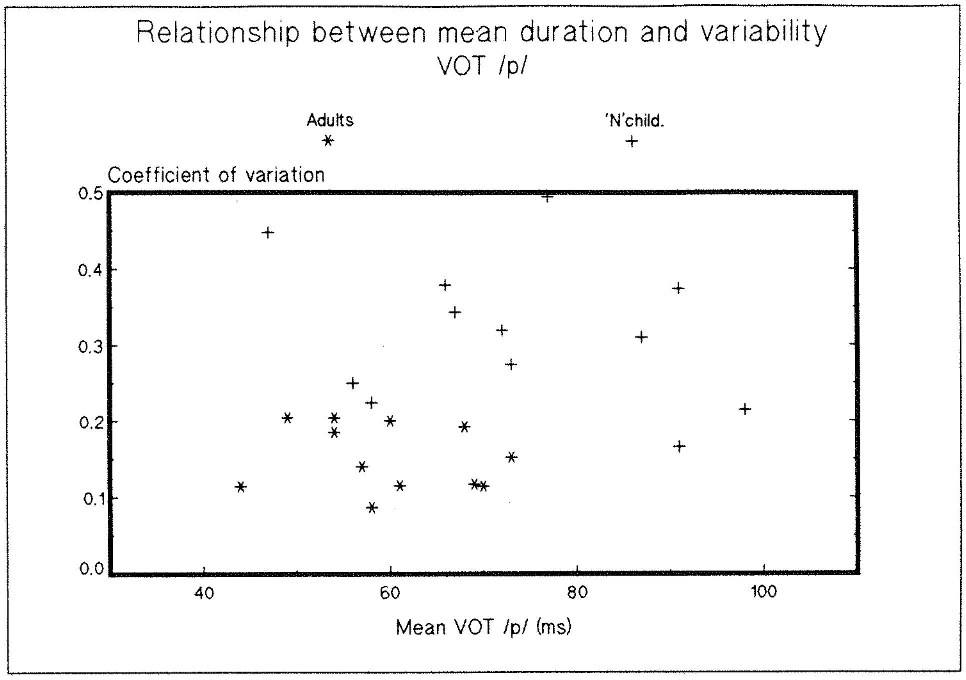

Figure 27. Scatterplot of the relationship between mean duration and variability of VOT for /p/ in the word 'playing' - A & N Groups.

The distribution of points on the scatterplot shown in figure 27 suggests a weak positive relationship between mean VOT and variability of VOT in the initial plosive in the word 'playing' across all subjects. This reflects the finding that adult subjects tended to exhibit relatively short and invariant VOTs for this consonant while the child subjects tended to exhibit relatively long and variable values. However, the value of 'r' (Pearson Coefficient of Correlation) was found to be small (=.21) and not of statistical significance.

When the distributions of scatterplot points within each subject group are considered separately the relationship between mean VOT and variability seems to be negative. That is, within each subject group shorter mean VOTs tend to be associated with higher degrees of variability. When Pearson Correlation Coefficients are derived this negative relationship is confirmed, but the values of 'r' (-.56 for the adult group data and -.3 for the child data) do not reach statistical significance at the .01 level.

The results of this investigation of relationship between mean (absolute) duration and temporal variability suggest that among the adult subjects there is little or no relationship between the absolute duration and variabiity of duration of particular phrase or segment measures but that among the child subjects there may be a negative relationship between mean duration and variability on some measures, particularly the measures of phrase duration and voice onset time of the initial plosive in the word 'two' where values of 'r' were found to be statistically significant. That is, on these measures at least, short absolute durations tend to be associated with high degrees of variability.

In view of the fact that it is generally accepted that longer, rather than shorter absolute durations tend to be associated with high temporal variability (Chernak & Schneiderman 1986; Smith Sugarman & Long 1983) it was felt to be appropriate to explore further the relationship between duration and variability in the child data. That is, the child data was examined to establish whether any relationship existed between subjects' mean phrase duration (speed of utterance) and overall temporal variability assessed across all measures. In the first instance the exploration was confined to the five child subjects, already referred to in 3.3.2.2. above, who exhibited the shortest mean phrase durations, that is whose mean phrase durations fell within the adult range of values.
Table 19 displays, for these five 'fastest' child speakers, ranks within their subject group on each measure of variability. Rank 1 indicates the lowest level of variability on a particular measure within the subject group.

WITHIN-GROUP RANKS FOR EACH SPECIFIED MEASURE:

SUBJ.	MEAN PHRS. DURN.	'C' PHRS. DURN.	'C' CLOS. /b/	'C' CLOS. /p/	'C' VOWEL DURN.	'C' VOT /t/	S.D. VOT /b/	'C' VOT /p/
N9	1	12	11	12	4	7	4	10
N10	2	11	9	7	5	4	11	8
N4	3	6	4	1	7	8	5	1
N12	4	10	10	10	10	5	8	7
N8	5	2	8	6	3	10	10	12

Table 19. Temporal variability of the five 'fastest' child speakers.

It can be seen that, with the exception of subject N4, there is a tendency for these fast child speakers to display high levels of temporal variability compared with their peers. That is a majority of their rankings are in the range 7 - 12. This observation suggests that further investigation across all subjects is warranted.

Figure 28 shows a plot of each subject's rank within subject group for the measure of phrase duration against average rank for six measures of temporal variabiity. Variability of VOT /b/ was excluded because, as discussed above, the method of assessing variability on this measure was inconsistent with that used for the other six measures.

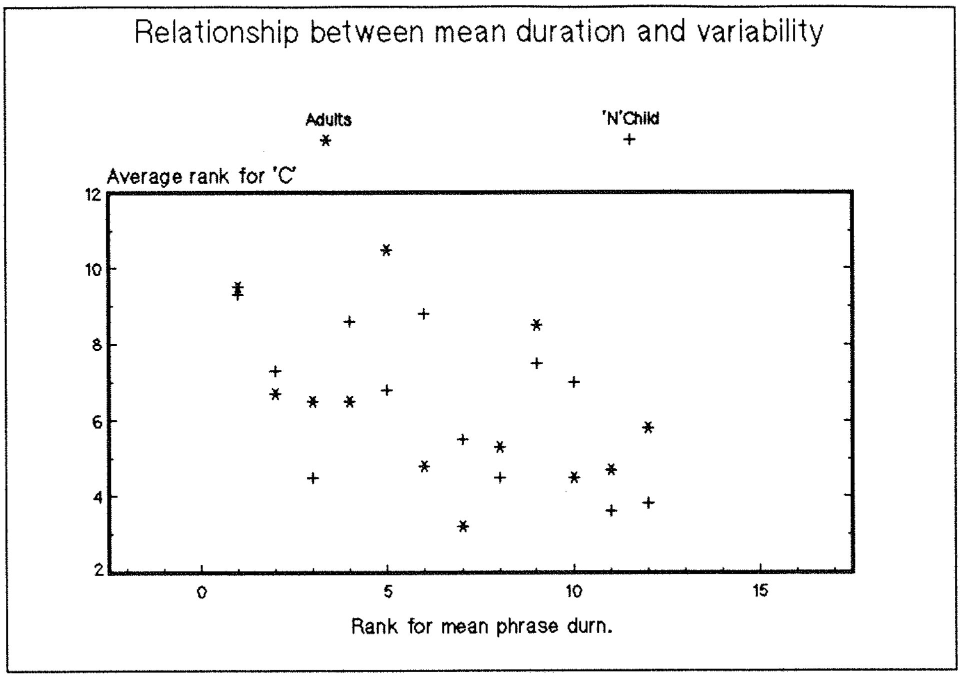

FIGURE 28. Scatterplot of the relationship between rank, within group, for mean phrase duration and average rank, within group, across six measures of temporal variability - A & N Group subjects.

If the point for subject N4, at the lower left extreme of the plot is excluded, a negative correlation is apparent for the child subjects between rank for mean phrase duration and average rank on measures of durational variability. A much weaker relationship is apparent among the adult subjects.

3.3.3. Summary of temporal acoustic measures.

This section summarizes the results of the measures of phrase and segment duration and temporal variability in the adult and normal child data in section 3.3.1. above and also the results of the additional analyses of the temporal acoustic measurements reported in section 3.3.2..

3.3.3.1. Absolute durations.

On each of the temporal measures the child subjects exhibited a greater spread of duration values than the adult subjects. That is, distributions of duration values across all child tokens tended to be wider and flater in form compared with the adults' narrower and more sharply peaked distributions.(See bar-charts, in figures 7, 9, 11, 13, 15, 17 and 19).

On all temporal measures, with the exception of the vowel duration measure, the distributions of child subjects' values were skewed to the right compared with the adult distributions, and many more N Group tokens fell above the adult ranges of duration values than fell below the adult range, reflecting a tendency towards longer durations in child subjects' tokens.

The measure of vowel duration in the word 'boys' seems to be an exception to this general trend, that is, on this particular measure there was a tendency for the child subjects to exhibit shorter durations than the adults.

Table 20, below, summarizes differences between adult and child group mean values for each temporal measure.

Mean durational measure	A Grp. Mean	N Grp. Mean	Significance. Value of 'p' (t-test)
Phrase	1340ms	1554ms	$p < .01$
Closure /b/	74ms	95ms	$p < .001$
Closure /p/	81ms	105ms	$p < .001$
Vowel ('boys')	220ms	205ms	not sig.
VOT /t/	68ms	70ms	not sig.
VOT /b/	16ms	21ms	not sig.
VOT /p/	60ms	74ms	$p = .017$

Table 20. Significance levels of differences between group mean durational measures - A & N Groups

Comparison of individual mean durations between the two subject groups demonstrated that on all the temporal measures (except the vowel duration measure) the child subject group exhibited longer mean durations than the adult subjects. The difference between group mean values reached statistical significance at the 1% level for the measure of phrase duration. Among the segmental measures, the two measures of consonant closure duration resulted in the most statistically significant differences between group means; both were significant at the 0.1% level. The VOT measures produced smaller differences between the subject groups; for the measure of voice onset time of the initial consonant in the word 'playing' the difference between group means was significant at the 5% level while for the remaining two voice onset time measures the difference between group means was in the same direction but did not reach statistical significance.

On the measure of vowel duration, in the word 'boys', there was a small difference between group means in the direction of shorter durations in the child group, but this difference did not reach statistical significance.

3.3.3.2. Temporal variability.

The results show highly statistically significant differences in individual temporal variability between adult and child subjects. This difference was found to be consistent across all the temporal measures involved. That is, t-tests indicated that differences between group mean values for intra-subject variability were significant at the 0.1% level for all the temporal measures with the exception of the measure of variability of VOT in the initial plosive in the word 'boys' for which a difference significant at the 1% level was found on the basis of group mean values for individual standard deviation.

Table 21 summarizes between group differences in temporal variability on all measures.

Measure	**A Grp. Mean**	**N Grp. Mean**	**Significance. Value of 'p' (t-test)**
Phrase	C = .044	C = .113	$p < .001$
Closure /b/	C = .105	C = .234	$p < .001$
Closure /p/	C = .106	C = .248	$p < .001$
Vowel	C = .074	C = .164	$p < .001$
VOT /t/	C = .118	C = .31	$p < .001$
VOT /b/	SD = 6 ms	SD = 12 ms	$p < .01$
VOT /p/	C = .152	C = .316	$p < .001$

Table 21. Significance levels of differences between group mean values for temporal variability measures - A & N Groups.

3.3.3.3. Additional analyses of temporal acoustic measures.

The additional analyses performed on the data indicated that:
(i) of the segmental measures made, the two consonant closure duration measures contribute most significantly to subjects' overall mean phrase durations, that is, that speakers who achieve short mean phrase durations do so chiefly by employing short consonant closure durations;
(ii) that the significantly higher levels of variability found in the child group data compared with the adult data cannot be regarded as a consequence of the longer phrase and segment durations exhibited by the child speakers, and can therefore be viewed as reflecting the children's relatively poor speech motor control abilities;
(iii) that among the child subjects, those who take, on average, the longest time to say the experimental phrase seem able to achieve the greatest control or precision over the timing features measured, whereas the fastest speakers achieve less precise temporal control.

3.4. RESULTS OF PERCEPTUAL (AUDITORY) ANALYSIS

This section reports the results of perceptual analysis of the data, that is, it examines the phonological form of the tokens from adult and child subjects. The first sub-section (3.4.1.) deals with the adult data: a count is made of the number of perceptually distinct speech segments in each adult token of the experimental phrase and occurrence of connected speech processes is analysed. That is, the occurrence of forms in connected speech which are reduced or simplified compared with careful 'citation' forms. Occurrence of elisions (omission of segments) are of particular interest since these affect the number of segments produced in an utterance and therefore have a bearing on measures of speech rate. Typical examples of elisions in adult connected speech include realisations such as [lɑsjɪə] (last year) in which elision of /t/ in the word 'last' occurs; [wɜl waɪ laɪ fʌnd] (World Wildlife Fund), in which elision of /d/ occurs; [fɹəmə hɒspɪtl] (from the hospital), in which elision of /ð/ in the word 'the' occurs. (Brown 1977, pages 61 & 64).

Section 3.4.2. deals with the child data: the number of perceptually distinct segments in each child token is counted, and reduced forms found in the child data are analysed across all child tokens and for each individual child subject. Differences of phonological form between the adult and child data are summarised in section 3.4.3. The final sub-section (3.4.4.) focuses on the relationship between temporal measures and phonological form in the child and adult data.

3.4.1. The adult data.

The adult group data consisted of 216 tokens of the phrase 'two wee boys are playing in the'.

3.4.1.1. Number of speech segments.

A count was made of the number of speech sound segments in each adult token of the experimental phrase. Judgement as to the number of distinct segments in a token was perceptually based but was assisted by examination of spectrographic and wave-form displays for discontinuities marking segment boundaries.

(One hesitant token, from subject A6 which involved repetition of a segment was excluded from this count).

The maximum number of perceptually distinct segments possible in the experimental phrase is 18: /tʰʉ wi bɔez aɾ pleɪŋ ɪn ðə /. (The diphthong in the word 'boys' was counted as a single segment.)

It was found that only 10 adult tokens consisted of this maximum number of 18 segments, while all other tokens consisted of fewer segments due to the occurrence of reduced forms and/or word omissions; that is, 169 adult tokens (79%) consisted of 17 segments, 33 tokens (15.4%) consisted of 16 segments, and 3 tokens consisted of 15 segments (see figure 29, below).
The connected speech forms found in the adult data are described below.

3.4.1.2. Reduced forms and word omissions.

Word omissions were found in 3 adult tokens; subject A8 omitted the word 'are' in one token and subject A11 omitted the word 'the' in 2 tokens. In all other adult tokens each word in the target phrase was realised.

Reduced forms were identified in the adult data affecting the words 'are'; 'playing' and 'the'.
The word 'are' consisted of two distinct segments in only 10 tokens, all from Subject A12, while in all other adult tokens it consisted of only one segment; that is of a vowel segment only, which was often an /r/-coloured vowel. This vowel was central-back, open and unrounded (/a/ or /aɾ/) in 21 adult tokens, while in the remaining 89.8% of adult tokens it was reduced to a neutral/central vowel /ə/ or /əɾ/ or to a back half-open vowel /ʌ/ or /ʌɾ/.

In 6.9% of adult tokens of the phrase the word 'playing' was realised as a monosyllable /pleŋ/ rather than disyllabically as /ple.ɪŋ/.

The adult speakers tended to realise the initial consonant of the word 'the' as a highly co-articulated reduced form for which there was no spectrographic evidence but which was perceived by a listener as marking an initial interdental fricative segment. Some 91.7% of adult tokens of the word 'the' fall into this category. The remaining adult tokens of the word 'the' were realised only as a neutral/central vowel /ə/ without any perceptual or spectrographic indication of an initial consonant segment.

One further reduced form was found in the adult data: that is subject A7 realised the initial consonant in the word 'boys' as a bilabial nasal /m/ rather than as a bilabial plosive /b/ in one token of the phrase.

In summary, the above analysis of the phonological form of the adult data has shown a high degree of uniformity among the 216 tokens of the experimental phrase: the most usual form of the experimental phrase spoken by adult subjects was:
/tʰʉ wi bɔez ər pleɪŋ ɪn ðə / consisting of 17 perceptually marked segments. Tokens which did not conform to this most usual pattern differed from it in one or more of the following ways:
i) the word 'are' was realised as an open, central-back vowel /ɑ/ or /ɑr/ in 10.2% of tokens, and in 10 of these tokens the word consisted of two distinct segments, and the word 'are' was omitted from 1 token;
ii) the word 'playing' was realised as a monosyllable /pleŋ/ in 6.9% of tokens;
iii) the word 'the' was reduced to a vowel segment /ə/ in 8.3% of tokens, and was omitted from 2 tokens.

3.4.2. The child data.

The data from normally developing child subjects consisted of 214 tokens of the experimental phrase. Two N group tokens were rejected from the data because noise on the recordings made analysis impossible.

In Appendix 3A analysis sheets for each N Group subject can be examined. The analysis sheets show realisations of each segment of the phrase in each token, in relation to the usual forms found in the adult data. Structural simplifications (deleted segments) are marked /∅/ and segments which were adult-like in form are not transcribed. The analysis sheets also show each child subject's mean phrase duration and rank within group for mean phrase duration; and the phrase duration (to the nearest 0.1seconds), the number of segments and the number of syllables are displayed for each token.

3.4.2.1. Number of speech segments.

Three hesitant tokens from child subjects, which involved repetitions of segments, were excluded from the segment count.
The barchart in figure 29 displays the numbers of segments found in the tokens from child subjects compared with tokens from adult subjects. It can be seen that several N Group tokens consisted of fewer segments than any of the adult tokens; that is, in 59 tokens from child subjects the occurrence of reduced forms and/or word omissions resulted in fewer than 15 segments being realised.

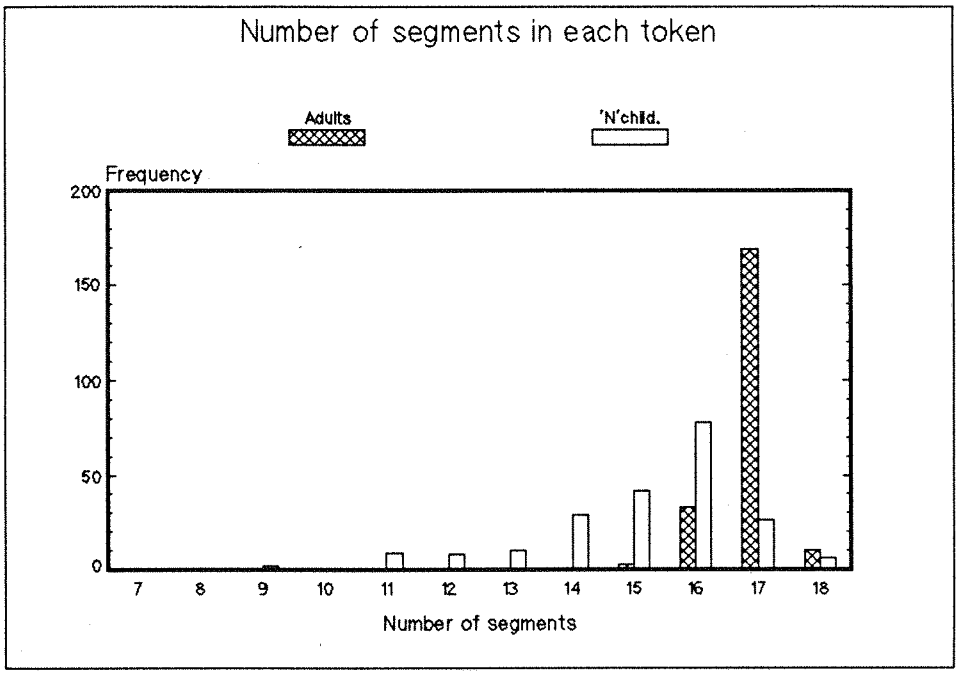

Figure 29. Numbers of segments in tokens of the experimental phrase spoken by A & N Group subjects.

3.4.2.2. Reduced forms and word omissions.

The occurrence of word omissions and reduced forms in the child data was analysed in relation to the analysis of the adult data. That is, a token from a child subject was regarded as adult-like in phonological form if it was identical to the usual form found in the adult data , or if it exhibited only those differences from this usual form which had already been identified in the adult data, (see

section 3.4.1. above).
Using this criterion it was found that 41 (19.2%) of the tokens spoken by the child subjects could be regarded as adult-like in phonological form, and a further 12 N Group tokens (5.6%) exhibited word omissions or word substitutions but were otherwise adult-like in phonological form, (see individual analyses in Appendix 3A).
The remaining 161 'N' Group tokens were characterised by a variety of non-adult-like realisations affecting syllable structure and individual consonant and vowel segments.
These are described below in order of occurrence in the experimental phrase:

The initial segment of the phrase (/t/ in the word 'two') was usually realised by child subjects as a voiceless, aspirated, alveolar plosive [tʰ] which was the form found in all of the adult tokens; 204 of the N Group tokens fell into this adult-like category for this segment.
There were 5 tokens in the N Group data in which this segment was heard as a voiced, unaspirated alveolar plosive [d]. This perceptually based judgement was confirmed by spectrographic and wave-form evidence showing short voice onset times.
In a further 5 'N' Group tokens noise on the recording or the extremely low volume employed by the speaker at the beginning of the utterance made transcription and measurement of this segment unreliable.

The vowel in the word 'two' was usually realised by the child subjects as a close, back, rounded vowel [u] or as a more fronted vowel [ʉ] which is more common in the local accent. These were the forms found in all of the adult tokens. 205 N Group tokens of the segment fell into this adult-like category.
There were 8 tokens from 'N' Group subjects in which the segment was reduced to a short, unrounded vowel [ə] or [ɪ] and in one token the vowel was prolonged, [ʉ:].

The next word in the experimental phrase ('wee') was omitted in 5 of the N Group tokens and in 24 tokens of the phrase spoken by child subjects the word 'little' was substituted for the word 'wee'. That is, there were 185 N Group tokens which included realisations of the word 'wee'.
In 181 of these the initial segment of the word was realised, as in

the adult data, as a labio-velar approximant [w]. In 2 of the child subject tokens the segment was deleted; that is, the word was realised as a vowel only; in one token it was realised as a voiced labio-dental fricative [v], and in one token as a labio-dental approximant [ʋ].

In 176 of the 185 'N' Group tokens of the phrase which included the word 'wee' the vowel was realised, as in the adult data, as a close,front, unrounded vowel [i]. There were 9 N Group tokens in which the vowel was reduced to a short, more central vowel [ɪ], and 1 token in which it was realised as a neutral vowel [ə].

The initial consonant segment of the following word, that is, /b/ in the word 'boys' was realised in all 214 N Group tokens of the phrase. In 184 of these it was heard as a voiced bilabial plosive consonant [b], as in all but one of the adult tokens. There were 3 N Group tokens in which the segment was heard as a voiceless, aspirated, bilabial plosive [pʰ] and in which this perceptually based judgement was confirmed by spectrographic evidence of long voice onset times. In a further 27 'N' Group tokens the initial segment in the word 'boys' was realised with extremely lax articulatory closure or with absence of closure which resulted in segments which were heard either as lax plosives [b̞]; as fricatives [β], [ɸ] or [ɣ]; or as continuants [w] or [ʋ]. In these tokens there was no spectrographic or wave-form evidence for the release of articulatory closure and no voice onset time measures or closure duration measures could be made (see sections 3.3.1.2 and 3.3.1.6. above).

The vowel in the word 'boys' was also realised in all of the 214 N Group tokens of the phrase. In 201 of these this vowel was regarded as being perceptually similar to the forms found in the adult tokens; that is, either [ɔe], which is usual in the local speech community, or [ɔɪ] or [ɔi].
In 1 N Group token the first element of the diphthong was reduced to a short and central vowel [əi] while in 6 tokens this first element was realised as an unrounded, back vowel, [ʌɪ], and in 3 tokens the first element was prolonged, [ɔ:e]. There were 3 instances in the N Group data in which the vowel in the word 'boys' was realised as a monophthong, [ɔ] (2) or [ʌ](1).

The final consonant segment of the word 'boys' (/z/) was omitted in 16 of the N Group tokens. In 186 of the remaining 198 tokens the segment was perceived to be adult-like in form; that is, a voiced alveolar fricative [z] or a devoiced alveolar fricative [z̥]. In a further 9 N Group tokens this segment was apparently produced with retracted articulatory placement and heard as [ʃ]; [ç]; [ʒ]; or [s̠], while in 3 tokens the segment was realised as a stop consonant [d] or as an affricated stop [dz].

The next word in the experimental phrase, 'are', was omitted in 89 of the tokens spoken by child subjects, and in a further 2 tokens the word 'is' was substituted. Of the remaining 123 tokens , there were 47 examples in which the word 'are' was realised as a central-back, open, unrounded vowel [ɑ] or [ɑ̃˞], (this compares with only 10 such examples in the adult data); and 76 examples in which the word 'are' was realised by a reduced vowel [ə], [ə˞], [ʌ] or [ʌ˞] as in the majority of adult tokens. There were no examples in the child data of the word 'are' consisting of 2 distinct segments.

It will be recalled that in most adult tokens, the next word of the phrase ('playing') was realised as a disyllabic structure [ple.ɪŋ], and that in 15 A Group tokens it was reduced to a monosyllable /pleŋ/. In contrast, in the 'N' Group data there were only 75 tokens in which the disyllabic structure of this word was preserved, and in the remaining 139 tokens it was reduced to a monosyllable.

The initial consonant cluster of the word 'playing' was judged to be adult-like in form in 184 of the 214 child tokens; that is, it was realised as an aspirated bilabial plosive followed by a lateral alveolar or post-alveolar approximant [pʰl]. In a further 17 N Group tokens one or other of the elements of the cluster was realised in a non-adult-like way: that is, the cluster was realised as [bl] (3); [fl] (8); [p̃ʒl] (1) or [pw] (5). In the remaining 13 child tokens the cluster was reduced to only one element; [p] (7); [b] (1); [f] (4) or [ɸ] (1).

The final consonant segment of the word 'playing' (/ŋ/)was realised in adult-like form in 78 of the child group tokens; that is, as a velar nasal [ŋ]. In a further 96 child tokens the segment was realised as an alveolar nasal [n]. There was one example in which a palatal continuant [j] was substituted and in the remaining 39 child tokens this segment was omitted.

In 186 child tokens the next word of the phrase, 'in', consisted of 2 segments, a vowel and an alveolar nasal. The vowel segment was an adult-like [ɪ] in all of these 186 tokens with the exception of the following: 2 realisation of the word as [ən], or [ʌn] ; 1 token in which both segments were perceived as being of exceptionally short duration [ɪ̆n̆] and 3 tokens in which the vowel segment was nasalised, [ɪ̃n] (2) and [ʌ̃n] (1). In a further 12 tokens the nasal segment was absent and in 15 tokens the vowel was omitted.

The final word, 'the', was omitted from 13 of the N Group tokens of the phrase. 87 (40.7%) of the tokens from child subjects exhibited realisations of the word 'the' which were similar to the usual adult form which was described above in section 3.4.1.2.; that is, they included an initial segment which was perceived as an interdental or dental fricative for which there was no spectrographic evidence.
In 91 of the 'N' Group tokens of the phrase the initial segment of the word 'the' was not perceptually apparent; that is, the word was realised as a vowel only. It will be recalled that this reduction was also found in some of the adult tokens (8.3%).
The remaining 23 'N' Group tokens exhibited 'stopped' realisations of the initial segment in the word 'the'. That is the word was realised as [də].

This analysis has proceeded on a 'word by word' basis in the interests of clarity; however there was evidence that some child subjects tended to treat the section of the phrase 'playing in the' as a single unit of motor planning and execution and their tokens exhibited reductions in the structure of this section of the phrase which are not readily apparent in a word by word analysis. A majority of the child tokens preserved the target structure of this section, that is, the section included 4 syllables, or exhibited only an adult-like reduction of the word 'playing' to a monosyllable /pleŋ/.

However, in some 47 child tokens this section of the phrase was characterised by more extensive reductions of structure. In 21 child tokens the section 'playing in the' was realised, for example, as [plen.ɪ.ɣə];
[ple.ɪn.ə]; [fe.ə̆n.ə] or [pe.ən.ə] (that is, it consisted of 3 syllables only, and one or more consonant segment was omitted).

In a further 23 tokens only 2 syllables were apparent, (for example [pe.nə]; [pwe.nə] and in 3 child tokens this section of the phrase was realised by only a single syllable, [plen] (2 tokens) and [ɸen] (1 token).

The foregoing analysis has discussed the phonological form of the child data as a whole but has not drawn attention to individual differences between subjects or to consistency/variability of phonological form within individual subjects' data.

The individual subject data analyses given in Appendix 3A reveal marked intersubject differences of phonological form among the child subjects. For example, it can be seen that subject N2 exhibited very few non-adult-like realisations of segments and only structural reductions which could be regarded as adult-like (had also been found in the adult data); that is, omission of the word 'are' (3 tokens) and deletion of the initial fricative in the word 'the', (13 tokens). This subject's tokens all consist of 7 or 8 syllables and between 15 and 17 perceptually distinct segments. At the other extreme of the child group data, subjects N10 and N9 both exhibited many non-adult-like realisations of consonant and vowel segments, including lax, undershot articulations and some excessively short realisations of segments, and also displayed a large number of structural reductions affecting segments which were never subject to deletion in the adult realisations of the phrase. The number of syllables in the tokens from subject N9 varied from 5 to 8 and the number of segments varied from 10 to 17; in subject N10's data the number of syllables in a token varied between 4 and 7 and the number of segments varied between 9 and 14. The other child subjects fall between these two extremes of performance, exhibiting varying numbers of non-adult-like structural reductions, systemic simplifications and lax, undershot articulations of segments.

A further striking aspect of the child data is the variation which is apparent within individual subjects' tokens of the phrase. Such intra-subject variation was not apparent in the adult data. Examination of the analysis sheets in Appendix 3A shows that in the majority of cases in the child data any given non-adult-like form occurs in only some tokens spoken by an individual child, while in other tokens that subject may exhibit a different non-adult-like form or realise the particular word or segment in an adult-like way.

3.4.3. Summary of the phonological characteristics of the child data in relation to the adult data.

In the adult data, reductions of phonological form were found only in the three words 'are', 'playing' and 'the', (apart from one isolated example). In marked contrast, in the child data, every segment of the phrase was affected by deletions or substitutions or undershot articulation in at least some of the tokens. That is, whereas the adult data was characterised by a high degree of uniformity of phonological form, the child data was characterised by diversity.

There were many more instances of omission of unstressed words in the child data: the word 'are' was omitted in 89 'N' Group tokens compared with one example in the adult data; the word 'the' was omitted in 13 child tokens compared with 2 examples in the adult data; and in addition there were 5 examples of omission of the word 'wee' and one omission of the word 'in' in the child data, neither of which occurred in the adult data.

In the child data reduced connected speech forms similar to those in the adult data were found to affect the words 'are', 'the' and 'playing', but the frequency of occurrence of these forms was dissimilar in the two subject groups; that is, the child subjects were more likely to reduce the word 'the' to a vowel segment only, (42.5% of child tokens compared with 8.3% of adult tokens); were more likely to reduce the word 'playing' to a monosyllable, (65% of child tokens compared with 7% of adult tokens); but the child subjects exhibited fewer tokens in which the vowel in the word 'are' was neutralised, that is in 47 child tokens this vowel was realised as a central-back, open vowel [ɑ] or [ɑʳ] compared with only 10 such examples in the adult data.

While 24.8% of the child group tokens were adult-like in phonological form, according to the criteria established in section 3.4.3., the remaining 75.2% of child tokens included non-adult-like structural and systemic simplifications of the phonological form of the target utterance. The section of the phrase 'playing in the' seemed to be particularly susceptible to structural reduction in the child data.

The analysis showed much greater individual variation of phonological form among the child subjects than among the adult subjects, with some children exhibiting few systemic or structural simplifications of the target utterance and mainly precise and adult-like articulation of segments, while other children's data was characterised by large numbers of imprecise articulations, phonemic substitutions and structural simplifications. Inconsistency of phonological form within individual's tokens of the phrase has also been shown to be a characteristic of the child data.

3.4.4. Relationship between temporal measures and phonological form

In section 3.3.2.3. above, it was shown that in the child data there was a general trend for short mean phrase durations to be associated with high temporal variability and long mean phrase durations to be associated with relatively precise temporal control; but no such relationship was apparent in the adult data. This section now explores the relationship between mean phrase duration and phonological form in the child and adult data; that is it explores whether any of the features revealed by perceptually based analysis of the data show systematic patterns of occurrence in relation to subjects' mean phrase duration.

Subjects within each group were ranked for mean phrase duration and a quantatitive analysis was made of the occurrence of reduced forms in each subject's data. These analyses are reported in tables 22 & 23. Table 22 lists the child subjects in order of rank for mean phrase duration and gives a quantatitive analysis of the phonological form of each subject's data; that is,
(i) the total number of segments deleted in the subject's tokens is given as a percentage of the total possible number of segments and,
(ii) the number of non-adult-like segment realisations in each subject's data is given as a percentage of the number of segments realised.
Non-adult-like segment realisations include realisations of a target segment by another English phoneme, for example
'two' -> [du], 'boys' -> [wɔez], 'playing' -> [fleɪŋ]; realisations

of a target segment by a non-English sound, for example 'boys' -> [βɔez], 'playing' -> [ɸen]; lax, undershot, or extremely short segment realisations, for example, 'boys' -> [b̥ɔež], 'two' -> [tʰə]; prolongations of segments and also segments affected by features of adjacent segments such as nasalisation of vowels in the section 'playing in the'. A decision was made against attempting to draw a distinction in this analysis between phonemic subtitution and other non-adult-like segment realisations since any such distinction, in the context of these data seemed to be arbitrary. That is, there did not seem to be a valid reason for making a distinction between, on the one hand, realisation of the initial segment of the word 'playing' as [f] or the initial segment of the word 'boys' as [w] or [p] , and , on the other hand, realisation of the initial segment of playing as [ɸ] or of the initial segment of boys as [ʋ] or [b̥].

Rank for mean phr.durn.	Subj.	% occurrence of segment deletions	% occurrence of non-adult-like segment realisations
1	N9	20%	19%
2	N10	37%	16%
3	N4	8%	6%
4	N12	17%	10%
5	N8	15%	14%
6	N6	13%	13%
7	N7	6%	1%
8	N3	8%	5%
9	N1	14%	14%
10	N5	3%	19%
11	N2	6%	1%
12	N11	8%	10%

Table 22. Phonological form in relation to rank for mean phrase duration - N Group subjects.

Rank for mean phr. durn.	Subj.	Number of reduced forms.
1	A7	7
2	A11	4
3	A10	0
4	A2	6
5	A4	0
6	A1	7
7	A6	0
8	A3	11
9	A8	1
10	A9	3
11	A12	0
12	A5	0

Table 23. Phonological form in relation to rank for mean phrase duration - A Group subjects.

Table 23 shows that in the adult data there was little if any relationship between mean time taken to execute the phrase and the occurrence of reduced forms. It is, however, of interest that the only idiosyncratic segment realisation in the adult data, which could be regarded as an articulatory error rather than an acceptable connected speech form, that is, realisation of the word 'boys' with an initial nasal segment, [mɔez], was found in the data from the adult speaker who exhibited the shortest mean phrase duration.

Table 22 however, shows that in the child data the highest occurrence of segment deletions and non-adult-like segment realisations tended to be found in data from those subjects who ranked at the upper end of the group for mean phrase duration. That is, among the six child subjects who ranked 1 - 6 for mean phrase duration (exhibited the shortest mean phrase durations) the average percentage occurrence of segment deletions was 18% and the average percentage occurrence of non-adult-like segment realisations was 13%: whereas, among the six subjects who ranked 7 - 12 for mean phrase duration the average percentage occurrence of segment deletions was 8% and the average percentage occurrence of non-adult-like segment realisations was 8%. The analysis therefore suggests a general trend in the child data for subjects who take the shortest mean time to produce the phrase to be least accurate in reproducing the target phonological form, that is, to exhibit high occurrence of structural reductions and non-adult-like segment realisations.

Not all the N Group subjects conform to this general trend as can be seen from table 22; Subject N4 who ranked 3 for mean phrase duration exhibited low occurrence of both segment deletion and non-adult-like segment realisations. It will be recalled that this same subject was also found to be an exception to the general trend in the N Group data in which short mean phrase duration was associated with high levels of temporal variability (see section 3.3.2.3. above). Table 22 also shows that among the child subjects who rank in the lower half of the range for mean phrase duration (who take relatively long mean times to execute the phrase), there are some percentage occurrence scores which are against the general trend. For example, Subject N1 had a relatively high occurrence of both segment deletions and non-adult-like segment realisations compared with similarly ranking subjects, and subject N5 had a high occurrence of non-adult-like segment realisations.

A similar relationship between phrase duration and accuracy of phonological form is also apparent within the data of some individual child subjects. For example, the data from subject N9 who ranked 1 for mean phrase duration included tokens in which many non-adult-like reductions occurred, but also included tokens which were much nearer the target phonological form of the phrase, and one token which was fully adult-like in form (see analysis sheet for subject N9 in Appendix 3A). When the durations of these various tokens were examined it was apparent that the most complete and accurate tokens were those with the longest durations and phonological accuracy was greatly reduced in tokens of very short duration. For example;

Token 3, [tʰʉwi bɔiz ə pleɪŋ ɪn ðə], (1410 ms)
Token 4, [tʰʉ wi bɔiz a fleɪŋ ɪn ðə], (1495 ms)
Token 12, [tʰʉ̆ w̆ə̆ b̆ɔɪz̆ plĕ.ɪ̆], (820 ms)
Token 13, [tʰʉ w̆i ʋɔɪz pleŋ̆ɪ], (890 ms).

Possible interpretations of these findings are discussed in section 3.6.2.5. below.

In summary the analysis of the relationship between temporal measures (mean phrase duration) and phonological form has identified a general trend in the child data for subjects who have short mean phrase durations compared with their peers to exhibit high occurrence of segment deletions and non-adult-like realisations of segments. That is, the analysis has identified a general trend for the fastest child speakers, who were previously found to display high levels of temporal variability compared with their peers, to be least accurate in achieving the target phonological form of the experimental phrase; and has also suggested that speed of execution of the phrase may be associated with loss of phonological accuracy within individual child subjects' repetitions of the phrase.
In contrast, in the adult data there is little to suggest a relationship between mean phrase duration and phonological accuracy.

3.5. SPEECH RATE IN THE ADULT AND CHILD DATA.

As was highlighted in Chapter Two, most previous studies which have focused on the measurement of speech rate have assumed that speech rate over any given utterance can be defined simply as the reciprocal of utterance duration. It was suggested in Chapter Two that such a measure may not in fact give a meaningful measure of speech rate, especially where connected speech data from young developing children is involved. That is, where the phonological structure of utterances is reduced with respect to target (citation) forms, the phonological structure (number of segments realised) must be taken into account when calculating a measurement of speech rate. In the current investigation the analysis of the phonological form of the data has revealed a large number and variety of structural reductions. Therefore, since not all tokens of the experimental phrase consist of the same number of segments, it would seem that speech rate cannot be defined in terms of phrase duration alone but must include consideration of how many speech segments are achieved in that time span.

The following definition of speech rate was therefore devised : speech rate over a token was defined as the number of perceptually distinct segments in the token divided by the duration of the token in seconds. Thus speech rate was expressed in segments/second. This measure was applied to both the adult and child data in the following manner: speech rate over each token of the experimental phrase was calculated by dividing the number of segments by the phrase duration (in seconds); mean speech rate was then calculated for each individual subject over all that subject's tokens of the phrase. Tokens which included hesitations were excluded from the measure.

Table 24 reports the results of this measure of individual mean speech rate for each adult and child subject, and gives the group range and group mean value for each of the two subject groups.

ADULT SUBJECTS		NORMAL CHILD SUBJECTS.	
SUBJECT	MEAN & RANGE	SUBJECT	MEAN & RANGE
A1	12.6 (11.9 -13.6)	N1	8.5 (7.6 -10.5)
A2	13.3 (12.5 -14.2)	N2	9.1 (7.7 -10.4)
A3	12.0 (10.3 -13.0)	N3	9.3 (8.3 -11.3)
A4	13.5 (11.4 -14.4)	N4	11.1 (8.4 -12.5)
A5	11.1 (10.2 -12.1)	N5	9.6 (8.4 -11.3)
A6	12.4 (11.8 -13.1)	N6	9.8 (8.5 -11.7)
A7	15.1 (13.3 -16.4)	N7	9.6 (8.6 -10.6)
A8	11.9 (11.0 -12.7)	N8	10.8 (9.1 -12.9)
A9	11.7 (10.7 -12.7)	N9	12.3(10.9 -13.1)
A10	13.8 (12.8 -14.7)	N10	9.8(8.2 -12.09)
A11	13.7 (11.4 -14.5)	N11	9.5 (7.5 -10-1)
A12	11.5 (10.6 -12.4)	N12	9.8 (7.0 -11.2)

GROUP MEAN FOR ADULT SUBJECTS = 12.7 segments/s (RANGE 11.1 - 15.1)

GROUP MEAN FOR CHILD SUBJECTS = 9.9 segments/s (RANGE 8.5 - 12.3)

Table 24. Speech rates (in segments/s) - A & N Groups.

The table shows that the range of values for mean speech rate among adult subjects was 11.1 - 15.1 segments/s, with a group mean value of 12.7 segments/s. The range of values among the child subjects was 8.5 - 12.3 segments/s, with a group mean value of 9.9 segments/s. Only two of the child subjects fell within the adult range of values and the remaining ten child subjects fell below the adult range.

A t-test was applied to evaluate the significance of the difference between the group means on this measure and the difference was found to be statistically significant at the 0.1% level ($p < .001$).
It will be recalled that the measure of mean phrase duration also resulted in a statistical difference between the adult and child subjects, but in that case the level of significance was lower ($p < .01$). The difference in the significance levels produced by

these two measures supports the view that a measure which takes account of the phonological structure of speech data is a more sensitive measure of speech rate than one which measures only total utterance duration.

3.6. SUMMARY AND DISCUSSION OF RESULTS.

This section begins with a summary of the results of all the acoustic and perceptual analyses of the data in the first phase of the investigation. In the remainder of the section (3.6.2. - 3.6.8.) each aspect of the results is discussed focusing on key differences which distinguished the adult and child data, the implications of these differences for the relative status of speech motor control in the two subject groups and the application of the findings to the second phase of the investigation involving a group of phonologically delayed pre-school children.

3.6.1. Summary of results

The results of the temporal acoustic measurements showed that:
(i) The child subject group as a whole exhibited significantly higher levels of intra-subject temporal variability compared with the adult group on all measures, and further analysis showed that child subjects were, in general, significantly less precise in their speech timing control when compared with adults who exhibited similar absolute durational values.

(ii) The child subjects tended to exhibit longer mean phrase and segment durations than the adult subjects, with the most significant differences between group means occurring on the measures of phrase duration and consonant closure durations.

(iii) Among the adult subjects no relationship was apparent between mean phrase duration (speed of utterance) and level of temporal variability; but among the child subjects there was some evidence to suggest that long mean phrase duration was associated with relatively low levels of temporal variability and, conversely, child subjects who executed the phrase in shorter time tended to be less precise in their temporal control.

The perceptually based analysis of phonological form showed that:

(i) Some 75% of tokens from the child subjects included structural and systemic simplifications and/or imprecise articulations which had not been found in the adult data, and analysis of individual child subjects' data demonstrated a wide range of inter-subject difference, and also inconsistency of phonological form within individual subjects' tokens of the phrase. Quantitative analysis of individual child subjects' data suggested a trend for short mean phrase durations, to be associated with inaccurate production of the phonological form of the target utterance, whereas in the adult data there was little evidence of such a relationship.

(ii) A measure of speech rate in segments/s, (which thus took account of the phonological structure of the data), demonstrated significantly higher speech rates in the adult subject group compared with the child group and resulted in a more statistically significant difference between the child and adult subject groups than the purely durational measure of mean phrase duration.

3.6.2. Discussion

3.6.2.1. Intra-subject temporal variability.

Intra-subject temporal variability was shown to be significantly higher in the child group than in the adult group, and this difference between the groups was found to be consistent across all the temporal acoustic measures. Since consistency of motor performance is regarded as an index of motor skill, this marked difference between the child and adult subjects on measures of individual variability strongly supports the view that adult speakers have superior speech motor control compared with young normally-developing children and such a finding is consistent with the findings of previous studies reviewed in Chapter Two.

The significantly higher degrees of temporal variability on the three VOT measures in the child data compared to the adult data is of particular interest, since there were fairly small (non-significant) differences between the two subject groups on mean duration for these measures (see 3.6.2.2. below). For example, on the measure of VOT in the initial plosive /t/ in the word 'two'; eleven child subjects were found to have mean VOTs within the adult range of mean values, but none of the child subjects achieved adult-like levels of temporal consistency.

This combination of findings suggests that although the child subjects were aware of the temporal characteristics which distinguish voiced and voiceless plosives and had sufficiently developed neuromotor skills to enable them to achieve approximately adult-like mean VOTs for a voiceless target, their speech motor control was not sufficiently mature to ensure that realisations of VOT intervals achieved adult levels of precision and consistency. That is, although the child subjects were 'aiming' for adult-like target VOTs they frequently 'missed' their targets and produced much more variable VOTs in multiple-token speech samples than the adult speakers.

3.6.2.2. Absolute phrase and segment durations.

The results of these measures were in the direction expected on the basis of previous studies reviewed in Chapter Two; that is, child subjects tended to have longer mean phrase and segment durations compared with adult subjects. This trend for longer durations in the child data again supports the view that adult speakers have superior speech motor skills compared with young normally-developing child speakers.

However, the extent of the differences in mean durations between the adult and child groups was not uniform across all the temporal acoustic measures, (see table 20, section 3.3.3.1. above) and possible explanations for these inconsistencies will now be considered. It must be stressed again that since durational measurements were made only for selected segments no comprehensive statement can be made about differences in segment durations in the adult and child data. However the results do suggest that certain types of temporal features tend to be prolonged in child speech compared with adult speech while other types of temporal features have quite similar mean values in child and adult speech. Although, as discussed in 3.6.2.1. above, children are more variable than adults in their production of all timing features.

The explanation for these differences may lie in the relative 'difficulty' of the articulatory manoeuvres required; that is, articulatory gestures which demand high degrees of neuromotor skill may tend to be executed more slowly in child speech resulting in longer durations, whereas less demanding combinations of articulatory gestures will be executed with relative ease by child subjects and mean durational values will therefore be similar in child and adult data. It is also possible that the phonemic status of a particular type of temporal feature may be important in determining whether that feature will have adult-like mean values in child speech. That is, a developing child speaker may learn first to approximate adult temporal values for those temporal features which he regards as the most perceptually salient, that is, which have a contrastive, meaning-carrying function., He may, only later, learn to produce adult like timing relationships which do not have a phonemic function. Both these factors may be relevant to the current data.

The most significant differences between group means were found in the measures of phrase duration and the two measures of consonant closure duration. That is, of the segmental durations considered in the investigation, consonant closure durations distinguished most significantly between adult and child subjects and correlated most highly with mean phrase duration.
Complete closure of the vocal tract for the production of plosive consonants results in change in the transglottal pressure differential (Rothenberg 1968, in Catts & Jensen 1983), and therefore the production of plosive consonants must necessitate adjustments in the laryngeal mechanism in preparation for voicing of subsequent segments. It is possible that the explanation for children's longer closure durations is that they are less skilful than adults in integrating these precise laryngeal adjustments with the actions of the oral mechanism, (have a less well-established co-ordinative structure), and therefore need to 'hold' the articulatory closure longer while adjustments are made. It may be that this is a particularly demanding set of actions and therefore is particularly likely to be performed slowly. It may also be that since consonant closure duration does not have a phonemic function, child speakers are 'free' to make economies in articulatory demand by prolonging closures. The following observation, in Hawkins (1984) makes a similar suggestion:

> Temporal regularities that do not function as primary perceptual cues, especially those that appear to provide no perceptual information at all, would be expected to be acquired as the child's articulatory abilities become more sophisticated. ....and we would expect them to appear later than distinctions that reflect primary perceptual cues.
> (Hawkins, 1984, p 327)

In contrast to the consonant closure duration measures, the three VOT measures (for one voiced and two voiceless plosive targets), showed much smaller group mean durational differences, which were in the direction of longer durations in the child data, but did not reach statistical significance at the 1% level. Such a result is, in fact, in agreement with the findings of previous studies. For example, Eguchi & Hirsch found no systematic change in VOT intervals with age in their data from normal children aged 3 - 13 years and adults. Such findings suggest that normally-developing children, from as young as 3 or 4 years of age, have deduced the temporal specifications associated with the voicing contrast in plosive consonants, and that they have the neuromotor ability to produce both short-lag and long-lag VOTs, although not with adult-like levels of precision and consistency. It may be that achieving adult-like values for VOTs is easier in some way than achieving adult-like closure durations and therefore VOTs approximate to adult values at an earlier stage than consonant closure durations; and/or it may be that children tend to 'concentrate' their neuromotor resources on matching adult VOTs rather than matching adult closure duration values because of the contrastive function of VOT values.

The range of VOT values exhibited by child subjects was wider than the adult range for all three voice onset time measures. In the initial plosive /t/ in the word 'two' one child subject (N5) produced some tokens with VOT in the short-lag range which were perceived as voiced and some which were perceived as unaspirated voiceless stops [t˭]. Similarly in the initial plosive /p/ in the word 'playing', VOT in three tokens from child subjects fell within the short-lag range and were perceived as voiced. Since in the majority of tokens from these same child subjects realisations of voiceless plosive targets were perceived as adult-like, it can be argued that these occasional short-lag (voiced) realisations were the result of lack of adequate neuromotor control rather than lack of phonological knowledge.

It was also found that the child data included some tokens in which plosives were realised with extremely long VOTs, outside the adult range of values for voiceless targets. This finding is consistent with some of the child subjects being at a stage of development, described by Macken & Barton (1980), at which children are able to achieve contrast between the VOT ranges associated with voiced and voiceless stops but do not have sufficiently mature neuromotor abilities to maintain adult-like control over the precise duration of voicing lag.

The results for the measure of vowel duration, in the word 'boys', were inconsistent with the other temporal measures; that is, the child subject group was found to have a smaller group mean value than the adult group on this measure, although the difference between group means was small and did not reach statistical significance. The explanation for this anomalous result may lie in the nature of the particular vowel segment and its phonetic context, that is, a diphthong. In the child data there were several examples of this vowel being realised as a monophthong, whereas in the adult data all tokens of the vowel were diphthongs. It may be that even when child tokens of the vowel were perceived as diphthongs there was a tendency for the second element to be produced with short duration compared with the adult realisations, and that a different finding would have resulted if a non-diphthongised vowel target had been examined.
A further possible explanation for the tendency to more short vowel durations in the child data may relate to the phonetic context in which the segment occurred; that is, preceding a word-final voiced fricative. It is well attested that in adult English speech, vowels preceding final voiced consonants are significantly longer in duration than the same vowels preceding final voiceless consonants, (Peterson & Lehiste 1960). It may be that some child subjects do not treat the final segment in the word 'boys' as a voiced target and therefore do not lengthen the preceding vowel. In the majority of both adult and child tokens there was little evidence on spectrographic or waveform displays of voicing continuing throughout this fricative segment; but although all adult tokens were perceived and transcribed as [z], there were several examples in the child data in which the segment was transcribed as [s] or [z̥] or as excessively short in duration [z̆], which might suggest that the child subjects were less certain of the voicing status of the fricative and therefore less likely to exhibit adult-like lengthening of the

preceding vowel.
However, any explanation for the results of the vowel duration measure can only be tentative on the basis of the measures made in the investigation.

3.6.2.3. Relationships between mean durations and temporal variability.

In the adult data there was no evidence of linear relationship between absolute durational measures and temporal variability, but in the child data there was a general tendency for short mean durations to be associated with high levels of temporal variability. The widely accepted view is that slow speech tends to be more variable than faster speech, and this view depends largely on results of studies which have examined changes in group temporal variability in relation to experimental manipulation of speaking rate, for example the studies by Smith, Sugarman & Long and by Chernak & Schneiderman reviewed in Chapter Two. Therefore, on the basis of findings of previous studies it might have been expected that any relationship between mean (absolute) durational values and temporal variability would be positive in direction; that is, the longest mean durations would tend to be associated with the highest levels of temporal variability.

The explanation for the discrepency between the findings of the current investigation and the findings of previous investigations probably lies in methodological differences. That is, the current investigation examines relationships between individual subjects' variability and durational measures at subjects' normal, preferred rates of speech rather than examining changes in group variability at different rates of speech in response to specific instructions. In other words the current investigation has addressed the question of whether any systematic differences in temporal variability are apparent in data from subjects who 'naturally' adopt a variety of different speeds of utterance. This question differs fundamentally from the question addressed by investigators such as Smith et al and Chernak & Schneiderman who investigated temporal variability changes when speakers were required to adopt non-preferred speeds of utterance.

In fact, even those studies do not unequivocally support the view that slow speech is more variable than faster speech, since in the study by Smith et al which measured variability of phrase duration and variability of selected syllable durations at subjects' normal speaking rate and at faster and slower rates it was found that although the measures of variability of phrase duration supported the view that slow speech is the most variable, the measures of syllable durational variability did not support this view; that is variability of syllable durations was lowest at speakers' normal rate of speech and increased at both faster and slower rates.

A possible interpretation of the findings in the current investigation, and of the finding on syllable duration variability in Smith's study, is that when given a free choice of speaking rate adult speakers adopt a speed which allows optimum control or precision within the limitations of each individual's motor speech abilities; hence no consistent relationship between speed and variability is apparent. On the other hand, young child speakers, still in the process of speech acquisition, with changing and developing neuromotor skills, with less experience to draw on and possibly with less awareness of their neuromotor limitations, are less able to select and maintain an optimum speed of utterance. Those child subjects in the current investigation who executed the phrase quickly compared with their peers tended to exhibit the least temporal precision and control perhaps because their attempted fast production of the phrase placed too great a demand on their neuromotor capabilities.

It will be recalled that one child subject (N4), was found to be an exception to the general finding that the 'fastest' child speakers were the most variable. Subject N4 ranked 3 in the child group for mean phrase duration and yet his mean rank for temporal variability across 6 temporal measures was 4.5 ; and when variability was compared in child and adult subjects who exhibited similar mean phrase durations it was found that subject N4 came closer to adult levels of consistency than any of the other child subjects considered. It seems reasonable to suggest that this child subject had more mature speech motor control abilities than the rest of the child subjects since he was able to execute the phrase within a time frame similar to adult speakers and achieve fairly low levels of variability as compared with his peers.

3.6.2.4. The phonological form of the data.

The analysis of phonological form of the child and adult data showed that reduced forms occurred in both sets of data, but while the adult data exhibited a high degree of uniformity and predictability of phonological form, with reduced speech forms confined to a few contexts, the child data exhibited wide diversity of phonological form with no predictable pattern of reduced forms which were found affecting all segments of the phrase.
The use of reduced connected speech forms by the adult speakers can be regarded as a strategy which maximises efficiency of speech production; that is, mature speakers employ a 'set' of reduced speech forms in connected speech which reduce the articulatory demands of an utterance without jeopardising its 'recoverability' by a listener. Hawkins P, (1984) suggests that such reductions should be regarded as "a kind of economy on the part of the speaker, who aims not to give more information than is necessary", (p165).

In the child data the adult 'set' of reduced speech forms which occurred in the particular context of the experimental phrase were all represented and tended in most cases to occur with greater frequency than in the adult data; but in addition to these adult-like reductions a great variety of other simplifications of the target utterance occurred which included reduction in the number of segments, reduction in the extent of articulatory movements, lax/undershot articulations, and assimilation of features between segments occurring in proximity; for example, in the section of the phrase 'playing in' where both nasal segments were often produced with alveolar placement.

It seems logical to assume that reductions (simplifications) of phonological form serve a similar function in both adult and child speech, that is, to reduce articulatory demand; but that young child speakers tend to employ such reductions more widely, and with less consistency and control. That is, it is suggested that the considerable differences in the phonological form of the data from the adult and child subject groups can be accounted for, at least in part, by the child subjects' more limited speech motor capacities, (which are evidenced by the results of temporal acoustic analysis in this and previous studies): when faced with the demands of reproducing an adult speech model, young children need to make more drastic reductions of form than adult speakers because their speech motor capacities are more limited. They also tend to reduce the form of an utterance in a less controlled and more 'haphazard' way than adults, partly because of the limitations of motor control and perhaps also partly because they lack awareness of which reductions are 'acceptable' to a listener and which reductions may jeopardise the intelligibility of the utterance.

Of course, the status of children's knowledge of the phonological rule system of the language cannot be ignored as a factor affecting the surface form of their utterances. That is, some of the differences between the adult and child data may be accounted for by child subjects specifying different (non-adult-like) targets in the plan for an utterance, because their underlying phonological organisation is non-adult-like. However, as has been suggested above, the majority of non-adult-like realisations found in the child data occurred in variation with adult-like realisations within individual subjects' data, which would tend to argue against an 'underlying phonological organisation' explanation for their occurrence.

3.6.2.5. Relationship between temporal measures and phonological form.

When phonological form in individual subjects' data was analysed in relation to subjects' mean phrase duration it was apparent that there was a general trend among child subjects for those who took the longest mean time to produce the phrase to be the most accurate in reproducing its phonological form; that is child subjects with longer mean phrase durations exhibited fewer segment deletions and fewer non-adult-like realisations of segments. A similar relationship between phrase duration and accuracy of phonological form was apparent **within** the data from some individual child subjects. However, there was little evidence of such relationship in the adult data.

Interpretation of these findings is not straightforward since it could be argued that the relationship between phrase duration and structural completeness in the child data is merely a statement of the fact that tokens which consist of fewer segments took less time to produce than more structurally complete tokens. If this is indeed a sufficient explanation then speech neuromotor capacity need have no bearing on the relationship between mean phrase duration and occurrence of segment deletions, since the time a child takes to produce the phrase is a consequence of the number of segments which has been specified in the phonological plan for the utterance.

However, other aspects of the results tend to argue against the sufficiency of this most simplistic interpretation of the relationship between utterance duration and structural completeness, and suggest that it only partially explains the relationship. First, analysis has shown that occurrence of non-adult-like segment realisations also tends to be highest in child subjects who execute the phrase in short mean time; and second, acoustic analysis has indicated that temporal consistency (precision) tends to be lowest in child subjects who execute the phrase in short mean time. These observations, taken together, suggest that when young child speakers attempt to execute an utterance within a time-frame which places excessive demand on their speech neuromotor capacities there tends to be loss of temporal precision and also loss of accuracy in the phonological form of the intended utterance, which is manifested in both structural reduction and non-adult-like realisations of segments.

Furthermore the apparent 'trade-off' between speed of execution of the phrase and phonological accuracy **within** individual child subjects' data would support this view. That is, it would be difficult to make a case for the structural reductions which occur in, for example, token 12 in Subject N9's data being the result of fewer segments being specified at a phonological planning level, since other tokens from this subject's data indicate that his underlying phonological knowledge is adequate for specifying the full adult form of the target utterance. It seems necessary therefore to regard both temporal aspects of children's utterances **and** the phonological form of their utterances, as being inter-related and linked to level of neuromotor ability. That is, there is a complex inter-relationship and inter-dependence between a developing child's abilities to maintain control over the overall time-frame of an utterance, ability to control segmental timing features and ability to maintain control over the implementation of the phonological form of the utterance, all of which reflect a child's level of maturity of neuromotor control for speech production.

The child subject (N4) referred to above (section 3.6.2.3.) was found to be able to execute the phrase without exhibiting marked reduction of phonological form although he was among the fastest child speakers, which tends to further support the assertion that his speech motor control abilities are advanced in comparison with his peers.

Table 22, above, also shows that two of the child subjects, N1 and N5, who were relatively slow in their execution of the phrase, were found to have relatively high occurrence of non-adult-like forms; that is, did not conform to the general trend. Both these subjects exhibited percentage occurrence of non-adult-like segment realisations which were comparable to those found in the fastest child speakers. However, when the pattern of non-adult-like segment realisations in the data from these two subjects is compared with, for example, the data from Subjects N9 and N10 (the two fastest child speakers) a possible explanation becomes apparent. That is, in the data from Subjects N1 and N5 a majority of non-adult-like segment realisations are accounted for by realisation of the final segment of the word 'playing' as an alveolar nasal [n] and by realisation of the initial segment in the word 'the' as a stop, [d]. These subjects show no evidence in their tokens of having the ability to produce adult forms of these two segments, at least, in the contexts in which they occur in the experimental phrase. That is, simplification of these two target segments seems to be 'obligatory' for these two child speakers in these particular contexts, irrespective of the speed at which the phrase is produced.
In contrast, the non-adult-like forms found in the data from subjects N9 and N10 tend to occur inconsistently; that is, in variation with acceptably adult-like realisations, which would imply that their non-adult-like segment realisations do not reflect an absolute limitation but occur only when they attempt fast executions of the phrase and hence place too great a demand on their ability to maintain articulatory precision.

3.6.2.6. Speech rate.

In previous studies which have investigated speech motor control in child and adult speech, measurement of utterance duration has been regarded as providing a valid measure of speech rate; that is, speech rate is assessed as the reciprocal of utterance duration.
However, the current investigation which has examined the phonological structure of the data as well as making temporal measures, has shown that such a definition of speech rate is inadequate, at least where the data are in a form in which the occurrence of connected speech processes is likely and/or where young child subjects, in the process of speech acquisition are involved.
The measure of speech rate adopted in this investigation which takes account of the phonological structure of the data has distinguished more significantly between the child and adult subject groups than the purely temporal measure of mean phrase duration. That is, it has shown that the child speakers not only tend to take longer mean times to produce the experimental phrase, but they also achieve fewer perceptually distinct speech segments in that longer time frame.
The highly significant difference in speech rate between the adult and normal child subjects on this measure of speech rate (in segments/s) supports and reinforces the view that speech neuromotor ability is poorer in young child speakers than in adult speakers, since rate of performance is regarded as a prime indicant of level of motor skill.

3.6.3. Summary and application of these findings to the evaluation of speech motor control in phonologically delayed children.

The first phase of the investigation which has made temporal acoustic and perceptually based analyses of multiple token speech samples from adult and normally developing young child subjects has shown that the key differences which distinguished the child subjects from the adult subjects were: higher levels of temporal variability, longer mean phrase durations and, in general, longer mean segment durations and slower speech rates. These findings are consistent with the view that young child subjects have poorer speech motor control abilities than adult speakers and are consistent with the results of previous studies which have investigated speech motor abilities in adults and

children.
Further differences which distinguished the child from the adult data were more widespread occurrence of reductions in the phonolgical form of the phrase and a tendency for both phonological inaccuracy and temporal imprecision (inconsistency) to be associated with short mean phrase duration. These differences can also be regarded as consistent with lower levels of speech motor ability in the child subject group and suggest that in the speech of young developing children both temporal characteristics **and** characteristics of phonological form are related to the development of speech neuromotor capacities.

The second phase of the investigation, reported in the following chapter, used the results from the first experiment to make a comparison between normal and phonologically delayed children on these indices of maturity of speech motor control. That is, in the second phase, speech data from phonologically delayed children was analysed using the same set of measures in order to evaluate the hypothesis that speech motor control in phonologically delayed children is less mature than in children of the same age who are developing speech normally. Those measures which distinguished most significantly between adult and normal child subjects in the first phase are regarded as most crucial in the second phase. In particular, the measure of speech rate which takes account of phonological form, is regarded as of particular importance in comparing speech motor ability in phonologically delayed and normal children, since marked differences in the phonological form of the data from these two groups of children is likely, and therefore a simple comparison of utterance duration may be of limited value.

CHAPTER FOUR

SECOND PHASE OF THE INVESTIGATION: PHONOLOGICALLY DELAYED CHILD SUBJECTS.

The second phase of the investigation examined data from a group of phonologically delayed children in the light of the result of the first phase reported in the previous chapter, in order to evaluate the main hypothesis that children delayed in phonological development have less mature speech motor control abilities than children of the same age who are developing speech normally.

The first section of the chapter states the specific aims of this phase of the investigation and sets out the specific experimental hypotheses devised on the basis of the results from the adult and normal child subject groups. The second section describes the method. Results of temporal acoustic analysis, perceptual analysis and speech rate measures performed on the data from phonologically delayed subjects are reported in the third, fourth and fifth sections and related to the results from the normal child subjects' data. The final section of the chapter summarizes all the results from this phase of the investigation and discusses them in relation to the specific experimental hypotheses described in section 4.1.

4.1. AIMS & EXPERIMENTAL HYPOTHESES

In the first phase of the investigation a number of differences were found in multiple token speech data from adult and normally developing child subjects. These results supported the view that speech motor control skills were relatively poorly developed in the child subjects compared with the adults. If the hypothesis, that speech motor control is less mature in phonologically delayed children than in children who acquire speech normally is correct, then greater differences on these same measures might be expected between phonologically delayed children's speech and adult speech than between normally developing children's speech and adult speech. That is, it might be expected that phonologically delayed subjects' data, in comparison with normal children's data would exhibit not only less adult-like phonological forms which is self-evident, but also longer mean phrase durations, longer mean segment durations (at least for those segments which had longer mean durational values in the N group than in the A group in phase 1), slower speech rates on a measure which takes account of phonological structure of the data, and higher levels of temporal variability.

The experiment in this second phase was therefore designed to evaluate these specific hypotheses:

(i) In multiple token connected speech data, phonologically delayed child subjects exhibit higher levels of temporal variability than normally developing children of the same age.

(ii) Mean phrase and segment durations are longer in multiple token speech data from phonologically delayed child subjects than in data from normal child subjects.

(iii) Phonologically delayed child subjects exhibit slower mean speech rates than normal child subjects on a measure of speech rate (devised in phase 1) which takes account of the phonological structure of the speech data.

This second phase also aimed to investigate the following aspects of the data which have a bearing on the main hypothesis:

(i) what similarities and differences of phonological form occur in the speech of phonologically delayed and normally developing child subjects in the context of the particular experimental phrase;

(ii) what relationships exist between measures of duration, durational variability and phonological form in data from the delayed child subject group and whether these relationships are similar to those found in the data from normally developing children in the first experiment?

4.2. METHOD

4.2.1. Subjects

The subjects in this experiment were 12 pre-school children, delayed in the acquisition of the speech sound system of English.
The group included four girls and eight boys with an age range between 3;8 years and 4;9 years (mean 4;3 years). The mean age and the sex ratio of this subject group matched that of the normal child subject group, Group N, described in the previous chapter.
The phonologically delayed children were about to take part in a separate study to evaluate a treatment procedure for phonological disorder which was to be carried out in the Department of Speech Pathology and Therapy at Queen Margaret College, Edinburgh. The children had been referred to the College Research and Demonstration clinic following a request to local Speech Therapists. All of the children had been referred to Community or Hospital based speech therapists because delayed acquisition of the sound system and the consequent lack of intelligibility was causing anxiety to parents and/or other carers. None of the children had yet received any remediation.
Sixteen children referred as the result of the request to therapists were considered for inclusion in the investigation.

The criteria for selection were:
(i) that their standard scores on the Edinburgh Articulation Test (Anthony, Bogle, Ingram & McIsaac, 1971) were less than 85, (that is equal to or below 1 standard deviation below the mean), and that their speech exhibited extensive occurrence of at least 3 simplifying phonological processes which would be expected to have been eliminated from the speech of normally-developing children of the same age. (Grunwell 1985 & 1987; Stoel- Gammon & Dunn 1985);
(ii) they achieved age appropriate scores on the Reynell Developmental Language Scales (Reynell, 1985) and the British Picture Vocabulary Scales (Dunn, Dunn, Whetton & Pintilie, 1982) which indicated that their language acquisition problems were confined to phonological/phonetic levels; that is, did not involve syntactic or semantic levels of language.
(iii) they had normal hearing, that is, they had passed all routine screening assessments of hearing and their parents and other carers had no doubts about their hearing ;

(iv) they had no known pathological history;
(v) English was the only language spoken in their homes and their families were local to the Lothian / Fife area of Scotland and spoke with the local Scottish accent of English.

Twelve of the sixteen available children met these criteria. Three children were excluded because their phonological acquisition was only marginally delayed; that is their EAT standard scores were within 1 standard deviation of the normal score for their age and they exhibited extensive occurrence of fewer than three non-age-appropriate simplifying phonological processes. One child was excluded because his father was Spanish and sometimes spoke his native language to the child.

Table 25 shows the age, sex and standard score on the EAT for each of the phonologically delayed child subjects, labelled P1 - P12.

See Appendix 1B for an analysis of the occurrence of simplifying phonological processes for each P Group subject made on the basis of the EAT data and a more extensive single-word speech sample.

Ref.No.	Sex	Age	EAT Standard Score
P1	M	4;9	61
P2	F	4;8	59
P3	M	4;7	48
P4	M	4;6	68
P5	M	4;5	56
P6	F	4;4	82
P7	M	4;4	67
P8	M	4;0	73
P9	M	3;11	81
P10	M	3;9	79
P11	M	3;8	64
P12	M	3;11	53

Table 25. Reference numbers, sex, age, and EAT scores - P Group subjects.

4.2.2. Data and the data collection procedure.

The same speech data were collected from the phonologically delayed subjects as was described in the first experiment. That is, data collected from each subject consisted of 18 tokens of the phrase 'two wee boys are playing in the', six in each of the following carrier sentences:

'two wee boys are playing in the sand'
'two wee boys are playing in the sea'
'two wee boys are playing in the snow'

The speech data were recorded under the same conditions and using the same recording equipment as described for the first phase of the investigation. The materials and method used for the collection of the data were the same as for the normally developing child subject group.

Thus a total of 12X18=(216) tokens of the phrase were recorded for analysis.

4.2.3. Analysis

Acoustic, perceptual and statistical analysis of the data from the phonologically delayed subject group employed the same instrumentation, the same procedures and the same measurement criteria as described in the first phase of the investigation.

4.3. RESULTS OF TEMPORAL ACOUSTIC ANALYSIS.

This section reports the results of the temporal acoustic analysis made on the speech data from the phonologically delayed child subjects and relates the results from each measurement to the results of the same measurements made in the first phase of the investigation.

4.3.1. Measures of phrase and segment duration and temporal variability.

4.3.1.1. Mean phrase duration and variability.

Ten P Group tokens were excluded from the phrase duration measure because of hesitations; three tokens from subject P3, two tokens from subject P4, one token from subject P7 and three from subject P10. A further token from subject P10 was excluded because of noise on the recording. Thus a total of 205 tokens of the phrase were available for measurement.

Figure 30 displays the distribution of phrase durations across all included tokens from phonologically delayed child subjects and includes the distribution of phrase durations found in the adult and normal child groups for comparison.
The bar-chart in figure 30 shows that the P Group subjects produced rather more tokens with phrase durations outside the adult range of values than did the normally developing children. A total of 79 P Group tokens had phrase durations above the range of values found among the adults' tokens, and 13 P Group tokens fell below the adult range. This compares with 63 N Group tokens above the adult range and 8 below. That is, the spread of values across the tokens spoken by the phonologically delayed child subjects was somewhat wider than in the data from the normal children.

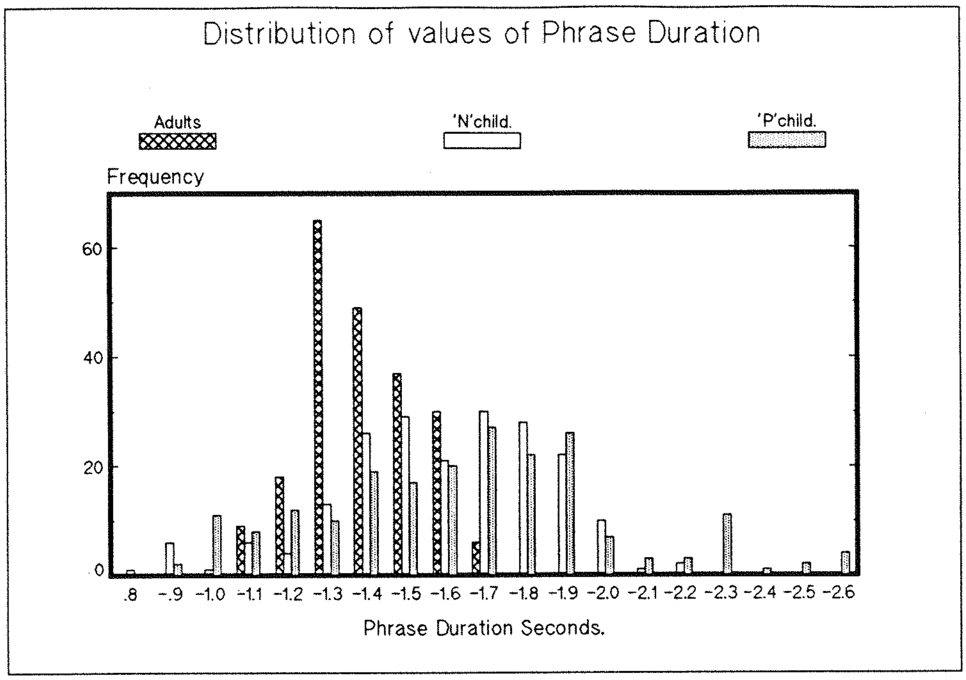

Figure 30. Distribution of phrase duration values - A, N & P Groups

Table 26 shows individual P Group subjects' ranges, means, standard deviations and coefficients of variation for this measure, and group mean values for mean duration and coefficient of variation. It can be seen that the phonologically delayed subjects exhibited mean phrase durations ranging from 1045 ms to 2312 ms with a group mean value of 1589 ms. This compares with a range of 1113 -1801 ms (group mean 1554 ms) in the normal child group in phase 1. This difference between the group mean values in the N and P subject groups was evaluated using a t-test and was not statistically significant ($p = .768$).
However, the phonologically delayed subjects exhibited a greater spread of mean phrase duration values, with two phonologically delayed subjects having mean values below the N Group range and two further P Group subjects exhibiting values above the N group range.

Table 26 also shows that values for phonologically delayed subjects' individual coefficients of variation for phrase duration ranged from 0.054 - 0.15 with a group mean of 0.095; this compares with the range for N group subjects (in phase 1) of 0.072 - 0.222 (group mean 0.113).

Figure 31 which displays individual means bracketed by standard deviations with coefficients of variation above each bracket, for subjects in the two child groups for comparison, illustrates that there was no systematic difference in individual variablity of phrase duration between the two child subject groups. A t-test confirmed that the difference between the group mean values for the coefficient of variation did not reach statistical significance, ($p = .254$).

Thus, in summary, the measure of phrase duration has shown that the phonologically delayed children exhibited more inter-subject variability of mean phrase duration and a greater spread of phrase duration values across all tokens than the normal child subjects in phase 1; but difference between group means in the P and N Groups was not statistically significant either for the measure of mean phrase duration or for the measure of intra-subject variability of phrase duration.

SUBJECT*	**RANGE (ms)**	**MEAN (ms)**	**S.D. (ms)**	**C (SD/M)**
P1	1350-1970(620)	1684	144	0.086
P2	1525-1885(360)	1727	126	0.073
P3(15)	1240-1630(390)	1421	97	0.068
P4(16)	1325-2125(800)	1600	196	0.123
P5	2130-2570(440)	2312	140	0.061
P6	1625-2130(505)	1862	112	0.06
P7(17)	860-1345(485)	1079	162	0.15
P8	915-1200(285)	1045	93	0.089
P9	1535-1925(390)	1769	95	0.054
P10(14)	1315-2045(730)	1516	192	0.127
P11	1115-1690(575)	1344	149	0.111
P12	1360-2465(1105)	1713	233	0.136

Group mean phrase duration = 1589 ms
Group mean coefficient of variation = 0.095

* Number of tokens given in brackets if fewer than 18.

Table 26. Duration and variability of duration of the experimental phrase - P Group subjects.

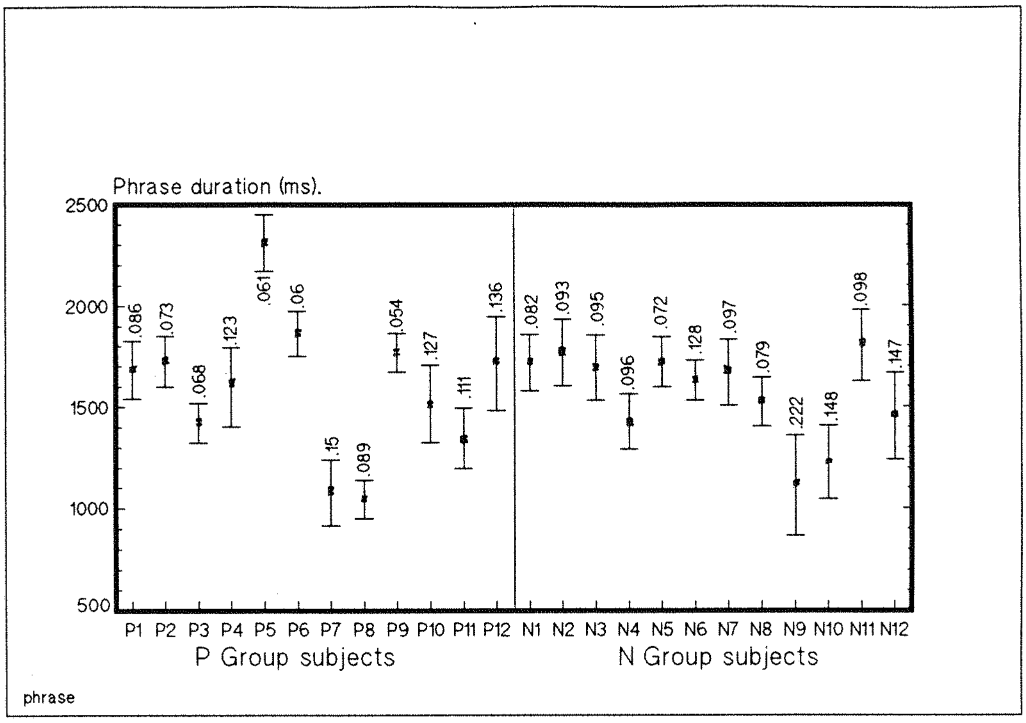

Figure 31. Mean phrase duration and variability of phrase duration - P & N Group subjects.

4.3.1.2. Mean duration and variability of closure of the initial consonant in the word 'boys'.

A total of twenty four tokens were excluded from this measure. Four tokens (two from subject P4, one from subject P7 and one from subject P10) were excluded because of hesitations which affected the consonant closure duration. A further twenty tokens were excluded because no burst of energy associated with release of closure was visible on either the spectrograms or the waveform displays; that is, either there was very lax closure or the segment was realised as a fricative [v] or [β], or as a continuant [w]. These twenty tokens included eight from subject P7, two from subject P8, one from subject P10, six from subject P11 and three from subject P12 .

Figure 32 displays the distribution of closure duration values for this consonant segment across all measureable tokens from phonologically delayed child subjects and includes the distribution of values on this measure in the adult and normal child data from phase 1 for comparison.
The bar-chart in figure 32 shows that many more tokens from phonologically delayed child subjects than from normal child subjects

exceeded the longest closure durations found in the adult data; that is, 51 P Group tokens compared with 11 N Group tokens. Thus, while the data from both child groups exhibited trends towards long closure durations compared with the adult data, this trend was stronger in the phonologically delayed children's data.

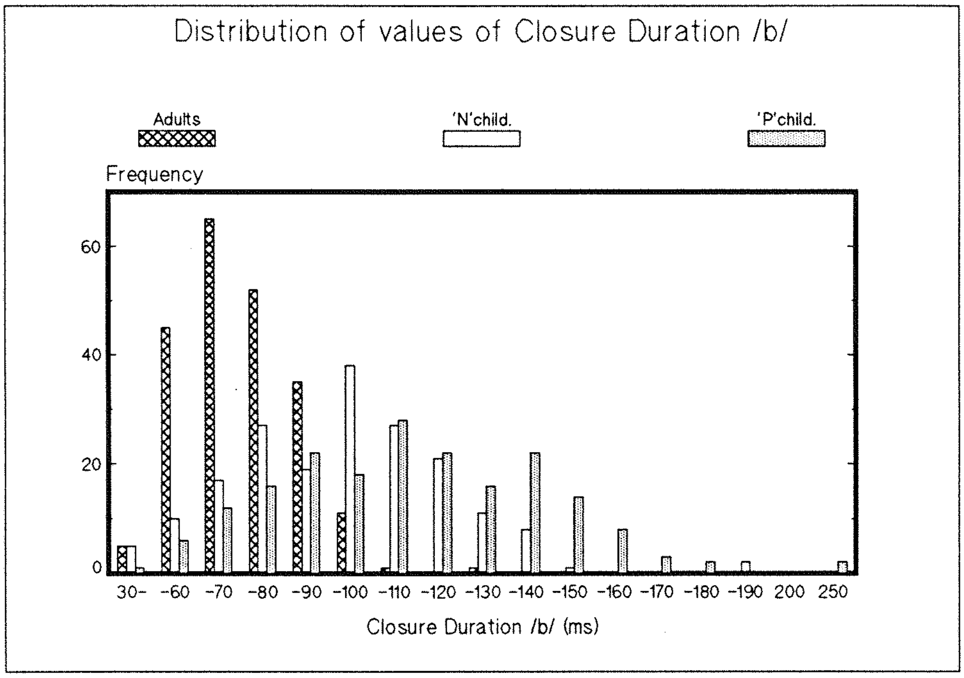

Figure 32. Distribution of closure duration values for /b/ in the word 'boys' - A, N & P Groups.

Table 27 shows individual phonologically delayed subjects' ranges, means, standard deviations and coefficients of variation on this measure, and also the group mean values for mean closure duration and coefficient of variation.
Referring to the table it can be seen that the phonologically delayed subjects exhibited mean closure durations for this segment which ranged from 74 - 149 ms with a group mean value of 111 ms; this compares with a range among N Group subjects, in phase 1, of 69 - 117 ms, (group mean, 95 ms). That is, there was considerable overlap between P and N Groups on the measure mean closure durations, but there was a greater spread of values in the P Group data, with four phonologically delayed subjects exhibiting longer mean durations than any of the normal child subjects. However, when a t-test was applied to evaluate the difference between the group means, the difference

between the P and N groups did not reach statistical significance (at the 5% level), ($p = .079$).

Table 27 also shows that phonologically delayed subjects had values for the coefficient of variation on this measure ranging from 0.107 - 0.292 with a group mean value of 0.19. This compares with a range among the N subjects group of 0.121 - 0.39 (group mean 0.234). Figure 33, which displays individual means bracketed by standard deviation with coefficients of variation above each bracket for subjects in the two child groups for comparison, illustrates that there was no systematic difference in individual variability of this consonant closure duration between the two child groups. When the difference between P and N group mean values for 'C' was evaluated using a t test, the difference between the groups was not statistically significant ($p = .176$).

Thus the results for the measure of closure duration in the initial plosive in the word 'boys' have shown that the P Group data included more tokens than the N Group data in which closure duration exceeded the adult range of values; that four phonologically delayed subjects exhibited longer mean durations than any of the normal child subjects, but the difference between the P and N Group mean values for mean closure duration was not statistically significant; and that group means for intra-subject variability of closure duration were not significantly different in the two child groups.

SUBJECT*	RANGE (ms)	MEAN (ms)	SD(ms)	C (SD/M)
P1	125-180 (55)	149	16	0.107
P2	110-270 (60)	145	35	0.241
P3	60-110 (50)	84	14	0.167
P4(16)	80-169 (60)	116	22	0.19
P5	95-155 (60)	129	16	0.124
P6	80-140 (60)	101	23	0.228
P7(9)	60-85 (25)	74	8	0.108
P8(16)	55-105 (50)	84	16	0.19
P9	85-160 (75)	113	21	0.186
P10(16)	90-270 (180)	137	40	0.292
P11(12)	55-125 (70)	99	21	0.212
P12(15)	60-140 (80)	95	23	0.242

Group mean closure duration = 111 ms

Group mean coefficient of variation = 0.19

* Number of tokens given in brackets if fewer than 18.

Table 27. Duration and variability of duration of closure for /b/ in the word 'boys' - P Group subjects.

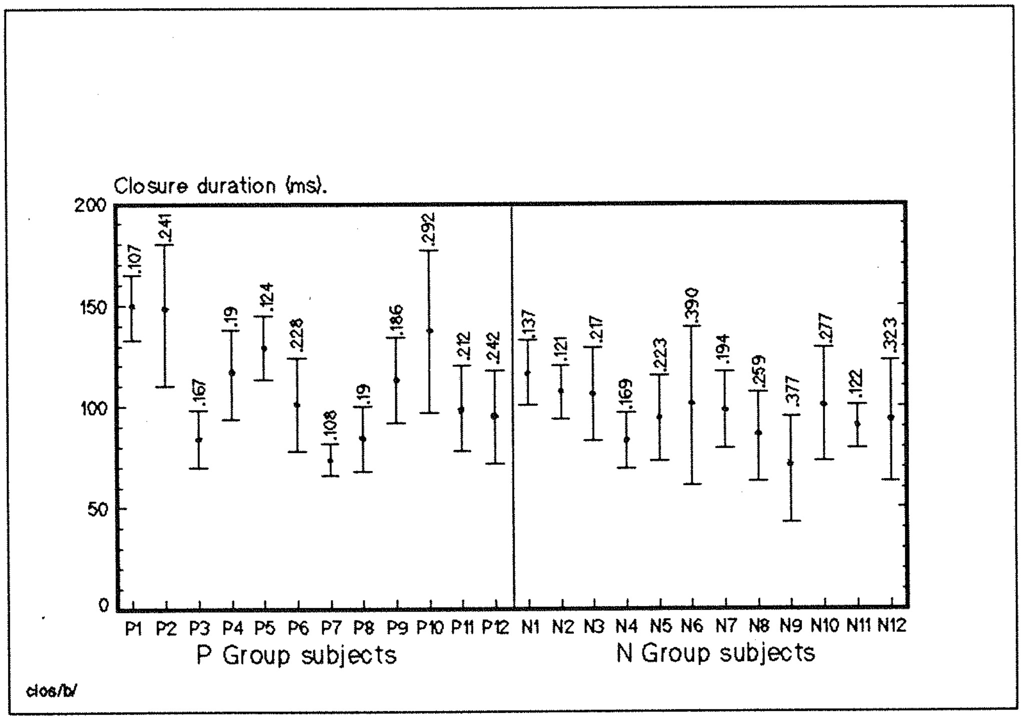

Figure 33. Mean duration and variability of duration of closure for /b/ in the word 'boys' - P & N Group subjects

4.3.1.3. Mean duration and variability of closure of the initial consonant in the word 'playing'.

A total of fifteen tokens were excluded from this measure. Four tokens (one from subject P3, two from subject P4 and one from subject P10) were excluded because of hesitations affecting the consonant closure duration. A further eleven tokens were excluded because no burst of energy associated with release of closure could be detected on spectrogram or waveform displays; that is, the segment was realised with very lax closure [p̜], or as a fricative, [f], [ɸ] or [β̞], (one token from subject P2, six from subject P7, one from subject P8, two from subject P11 and one token from subject P12).

Figure 34 displays the distribution of the values of the closure duration for this segment across all measureable tokens from phonologically delayed child subjects and includes the distribution of values on this measure in the adult and normal child data from phase 1 for comparison.
The bar-chart in figure 34 shows that while the distribution of values on this measure was fairly similar for the two child subject groups, extremely long values occurred more frequently in the data from phonologically delayed subjects. That is, while 42 N Group tokens had closure durations above the adult range, there were 61 P Group tokens in this category and 12 of these exceeded the normal children's range of values. It should be noted, however that 10 of these were all spoken by one subject (P1) and may therefore be of limited significance.

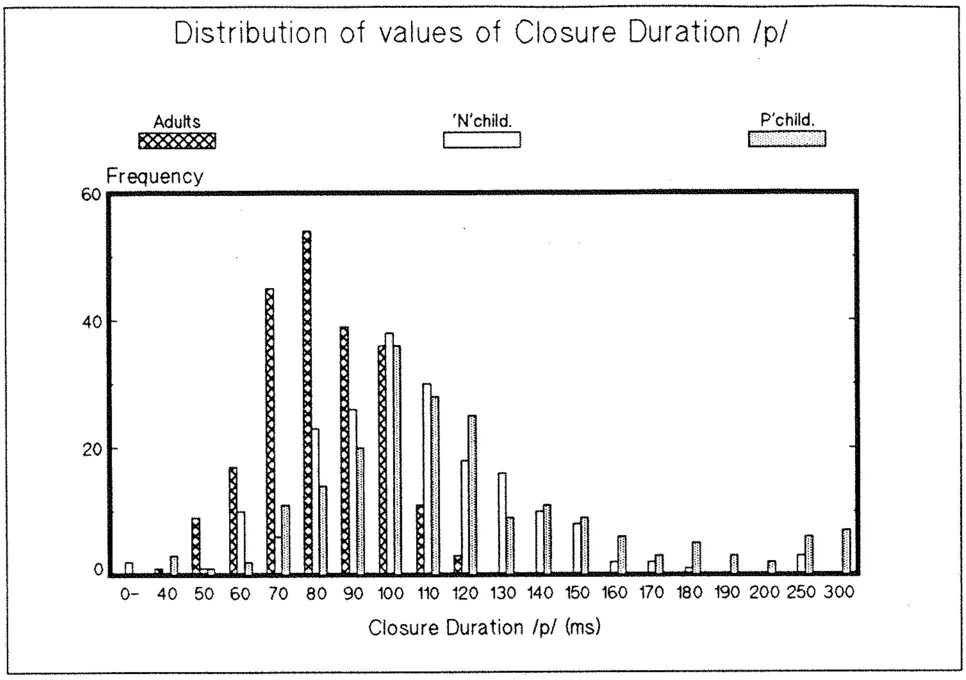

Figure 34. Distribution of closure duration values for /p/ in the word 'playing' - A, N & P Groups.

Table 28 shows individual P Group subjects' ranges, means, standard deviations and coefficients of variation on this measure and also group mean values for mean closure duration and variability. Referring to this table it can be seen that mean closure durations for this segment in the phonologically delayed subject group ranged from 84 - 227 ms with a group mean of 120 ms.; This compares with a range of 80 -130 ms (group mean 105 ms) in the normal child group. There was, therefore, considerable overlap between the mean closure durations found in the two child groups, with only one phonologically delayed child (P1) falling outside the N Group range. A t-test was applied to evaluate the difference between the group means in the two child subject groups and the difference was not statistically significant. (p = .218).

Table 28 also shows that phonologically delayed subjects' individual coefficients of variation ranged from 0.127 - 0.443 with a group mean value of 0.289. This compares with a range among normal child subjects of 0.165 - 0.338 (group mean 0.248). There was, therefore a greater spread of values for 'C' in the phonologically delayed group than in the normally-developing group, with one P Group subject (P5) exhibiting lower variability on this measure than any of the N Group subjects and four P Group subjects showing higher levels of variability than any of the normal child subjects. A t-test showed that the difference between the group means for coefficient of variation was not statistically significant, ($p = .189$). Figure 35, which displays individual means bracketed by standard deviation for subjects in the two child groups for comparison, illustrates that there was no systematic difference in individual variability between the two child subject groups.

Thus results for the measure of closure duration in the initial plosive in the word 'playing' have shown a weak trend towards longer closure durations in phonologically delayed children's data and greater inter-subject differences in mean duration among P Group subjects than among N Group subjects, but no statistically significant difference between group means on the measure of mean duration. There was no statistically significant difference in intra-subject variability between the two child subject groups.

SUBJECT*	**RANGE (ms)**	**MEAN (ms)**	**SD (ms)**	**C (SD/M)**
P1	160-290 (130)	227	47	0.207
P2(17)	75-190 (115)	119	33	0.277
P3(17)	80-180 (100)	107	25	0.234
P4(16)	80-160 (80)	118	52	0.441
P5	95-150 (55)	110	14	0.127
P6	85-190 (105)	120	25	0.208
P7(12)	40-175 (135)	84	37	0.441
P8(17)	50-160 (110)	85	27	0.318
P9	90-170 (80)	129	23	0.178
P10(17)	40-260 (220)	116	47	0.405
P11(16)	70-195 (125)	104	31	0.298
P12(17)	70-295 (225)	115	51	0.443

Group mean closure duration = 120 ms
Group mean coefficient of variation = 0.298
* Number of tokens given in brackets if fewer than 18.

Table 28. Duration and variability of duration of closure for /p/ in the word 'playing' - P Group subjects.

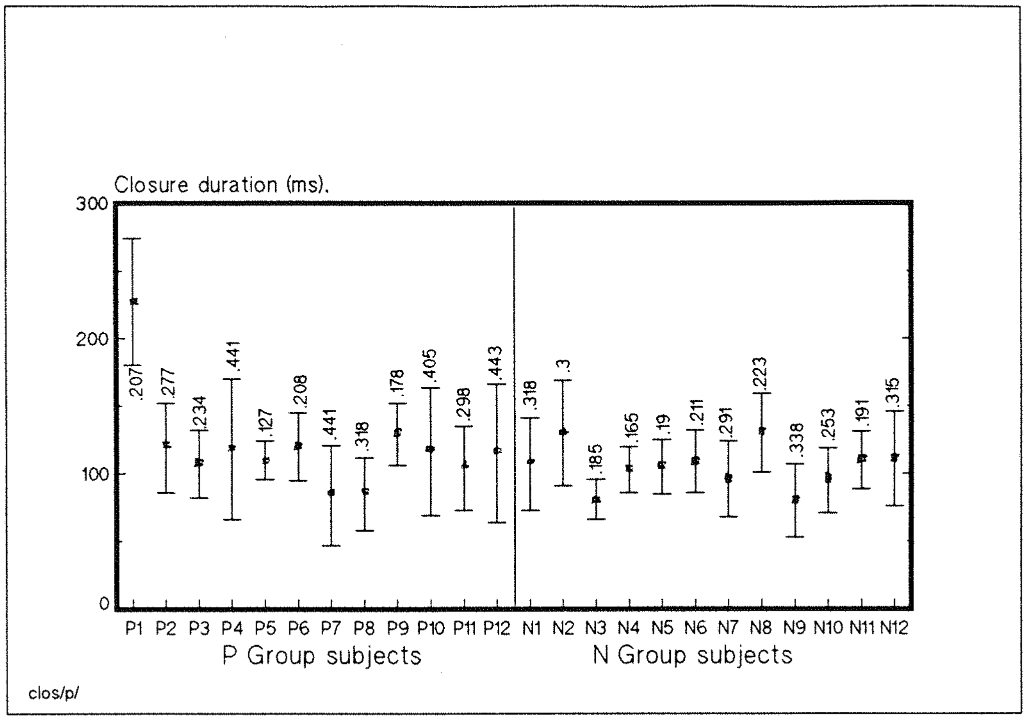

Figure 35. Mean duration and variability of duration of closure for /p/ in the word 'playing' - P & N Group subjects.

4.3.1.4. Mean duration and variability of the vowel in the word 'boys'.

Figure 36 displays the distribution of values of the duration of the vowel in the word 'boys' across all tokens from phonologically delayed subjects (there were no exclusions from this measure). The figure also displays the distribution of values on this measure in the adult and normal child subject groups from phase 1 for comparison.

The bar-chart in figure 36 shows that the range of vowel durations was very similar in the two child subject groups, with a tendency for the normally developing subjects to favour vowel durations in the lower half of the adult range while the phonologically delayed subjects were more likely to exhibit durations in the upper half of the adult range.

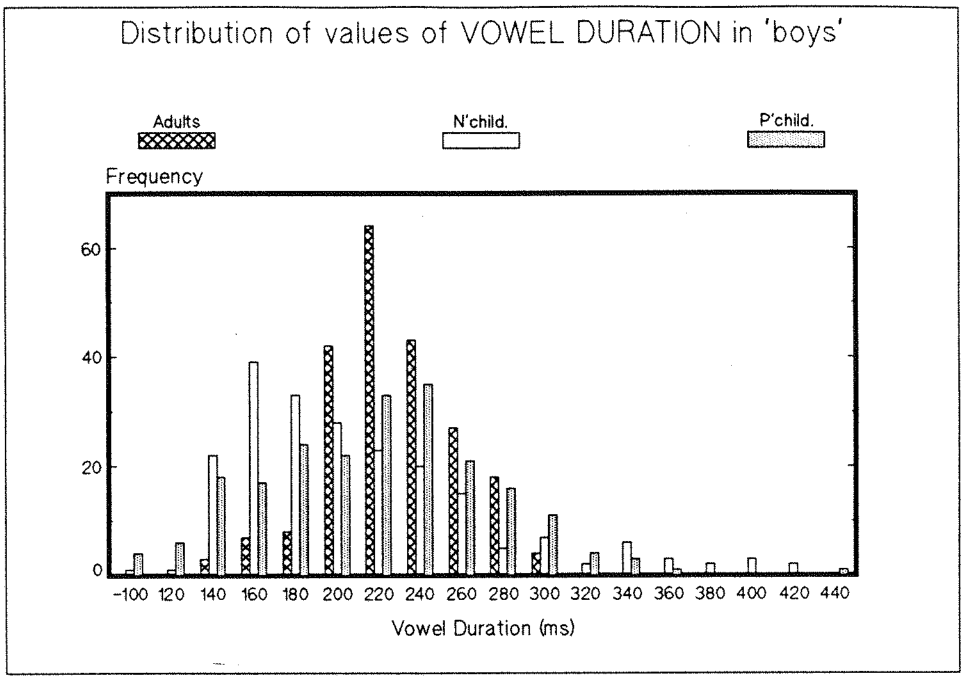

Figure 36. Distribution of values for the duration of the vowel in the word 'boys' - A, N & P Groups.

Table 29 shows individual P Group subjects' ranges, means, standard deviations and coefficients of variation on this vowel duration measure as well as group mean values for mean vowel duration and coefficient of variation.

The table shows that among the phonologically delayed subjects, mean values for this measure ranged from 132 - 278 ms with a group mean value of 213 ms. This compares with a range of 144 - 336 ms (group mean 205 ms) found in phase 1 in the normal child group.

Phonologically delayed subjects behaved very like the normally developing subjects on this measure in that in each of the two child groups three subjects had values for mean vowel duration which were below the adult range and two P Group subjects and one N Group subject had values which were longer than any of the adult subjects.

A t-test confirmed that there was no significant difference between the group means for mean vowel duration in the two child groups, (p = .703).

Table 29 also shows that individual coefficients of variation among the phonologically delayed children ranged from 0.082 - 0.356 with a group mean value of 0.161. This compares with a range in the normal child group of 0.125 -0.238 (group mean 0.164). There were greater inter-subject differences among the phonologically delayed subjects than among the normally-developing child subjects, with four P subjects' values for 'C' falling below the N Group range and two P Group subjects' values falling above the N Group range. However, a t-test showed that the group mean values for the coefficient of variation of the duration of the vowel in 'boys' were not significantly different in the two child groups, (p = .894). Figure 37 displays individual means bracketed by standard deviation, with coefficients of variation above each bracket, for subjects in the two child groups for ease of comparison and illustrates that there was no systematic difference in individual variability between the two child groups on this measure.

Thus, results for the measure of vowel duration in the word 'boys' have shown a similar range of vowel durations in the data from the two child subject groups and no significant difference between the group means for mean duration or for individual variability in the two child groups.

SUBJECT	RANGE (ms)	MEAN (ms)	SD (ms)	C (SD/M)
P1	170-225 (55)	196	16	0.082
P2	180-280 (100)	234	29	0.124
P3	200-280 (80)	229	20	0.087
P4	170-630 (460)	278	99	0.356
P5	225-340 (115)	265	35	0.132
P6	195-300 (105)	235	30	0.128
P7	130-180 (50)	153	18	0.118
P8	90-180 (90)	132	20	0.152
P9	220-310 (90)	264	29	0.11
P10	95-265 (170)	152	45	0.296
P11	170-330 (160)	224	41	0.183
P12	140-250 (110)	192	31	0.161

Group mean vowel duration = 213 ms
Group mean coefficient of variation = 0.161

Table 29. Duration and variability of duration of the vowel in the word 'boys' - P Group subjects.

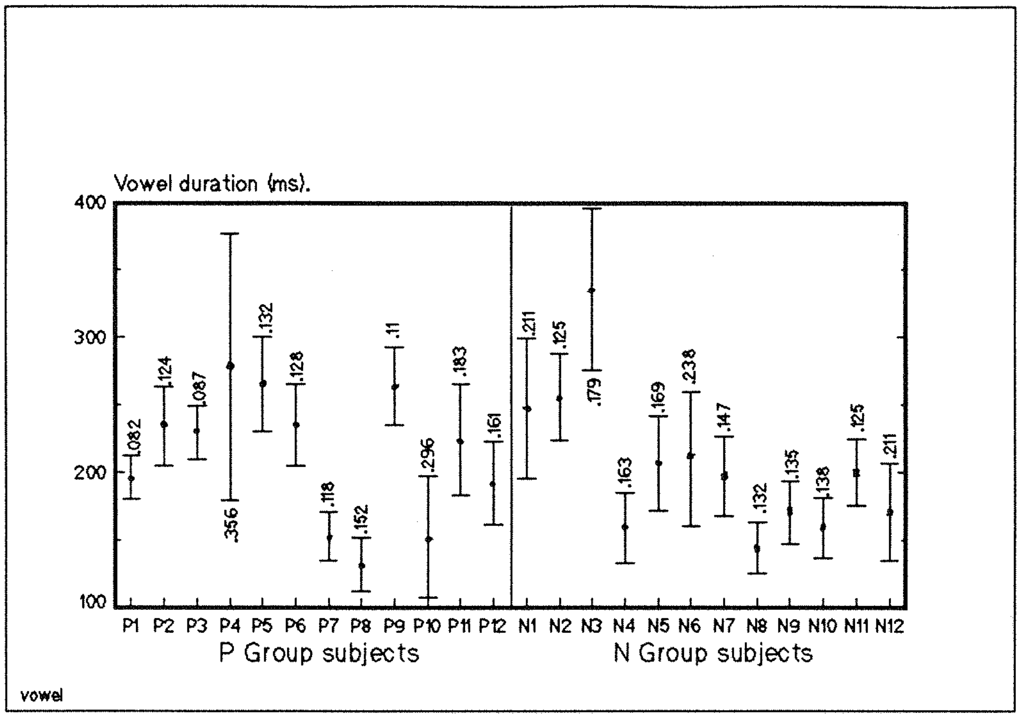

Figure 37. Mean duration and variability of duration of the vowel in the word 'boys' - P & N Group subjects

4.3.1.5. Mean duration and variability of voice onset time in the initial consonant in the word 'two'.

A total of twenty two tokens were excluded from this measure. All tokens from subject P3 were excluded because this child exhibited a process of glottal replacement in this context, that is /tu/ -> [ʔu]. One token from subject P4 was excluded on the same grounds. Two tokens from subject P10 which had noise at the beginning of the recording, making the VOT measurement unreliable, were also excluded, as well as one token from subject P11 in which the VOT measurement was unreliable because the first word of the utterance was spoken at very low volume.

Figure 38 displays the distribution of the values of the VOT of the initial consonant in the word 'two' across all measureable tokens from phonologically delayed subjects. The figure also displays the distribution of values for this measure in the adult and normal child subject groups, from phase 1, for comparison.
The bar-chart in figure 38 shows that phonologically delayed subjects produced more tokens of this consonant with very short VOT's and more tokens with very long VOTs than normally developing subjects. That

is, 31 tokens from P Group subjects and 12 N Group tokens had VOTs for this plosive below the adult range of values and 27 P Group tokens, compared with 7 N group tokens exceeded the upper limit of the adult range.

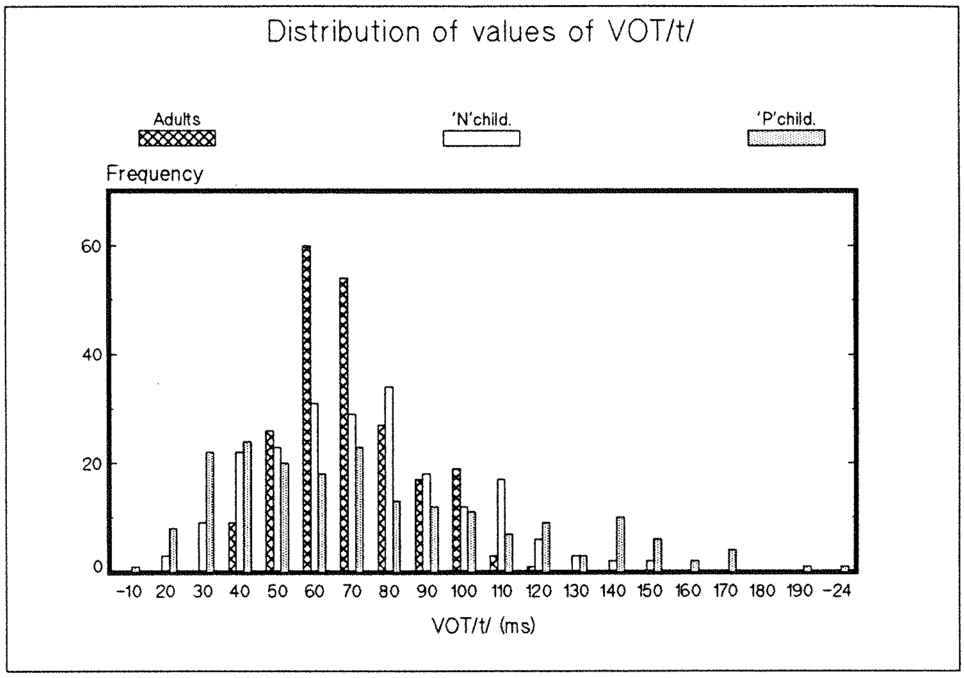

Figure 38. Distribution of VOT values for /t/ in the word 'two' - A, N and P Group subjects.

Table 30 shows individual P Group subjects' ranges, means, standard deviations and coefficients of variation on this VOT measure and also group mean values for mean VOT and coefficient of variation.

The table shows that mean VOTs in the phonologically delayed subject group ranged from 33 - 143 ms with a group mean value of 74 ms. This compares with a range in the normally developing child group of 42 - 98 ms (group mean 70 ms). That is, there was very little difference between group means for the two child subject groups on this measure, and a t-test confirmed that the difference was not statistically significant, (p = .713). There was, however a greater spread of values for mean VOT among the phonologically delayed child subjects than among the normal child subjects, with 3 P Group subjects having mean VOTs below the N Group range of values and 2 P Group subjects exhibiting mean VOTs above the N Group range.

Table 30 also shows that the coefficient of variation (individual variability) of VOT for this segment in the phonologically delayed

group ranged from 0.259 - 0.46 with a group mean value of 0.377. This compares with a range among normally developing child subjects of 0.183 - 0.452 (group mean 0.31). A t-test showed that the difference between the group means for intrasubject variability was statistically significant at the 5% level (p = .035).
Figure 39 displays individual means bracketed by standard deviation with coefficients of variation above each bracket for subjects in the two child subject groups for ease of comparison and illustrates the absence of any systematic difference between the two groups on measures of mean duration or variability. The figure also illustrates the greater spread of mean VOT values in the P Group compared to the N Group.

In summary, the results of this measure of voice onset time in the initial plosive /t/ in the word 'two' have shown that the phonologically delayed subjects' data included more extreme VOT values than the normal child data; that is, more instances of VOTs which fell above and below the adult range of values and that there was a wider range of mean VOT values among phonologically delayed subjects than among normal child subjects. The difference between the group means for mean VOT was not statistically significant while the difference between group means for individual variablity in the the two child subjects groups was significant at the 5% level.

SUBJECT*	RANGE (ms)	MEAN (ms)	SD (ms)	C (SD/M)
P1	40-140 (100)	87	29	0.333
P2	30-130 (100)	77	30	0.39
P3$	-	-	-	-
P4(17)	20-70 (50)	37	12	0.324
P5	90-240 (150)	143	37	0.259
P6	40-130 (90)	73	27	0.37
P7	30-140 (110)	65	26	0.4
P8	5-120 (115)	65	30	0.46
P9	15-75 (50)	33	14	0.424
P10(16)	20-80 (60)	41	18	0.439
P11(17)	30-150 (120)	84	32	0.381
P12	50-170 (120)	110	40	0.364

Group mean VOT = 74 ms

Group mean coefficient of variation = 0.377

* Number of tokens given in brackets if fewer than 18.

$ SUBJECT P3 - Glottal replacement of this segment occurred in all tokens.

Table 30. Duration and variability of VOT for /t/ in the word 'two' - P Group subjects.

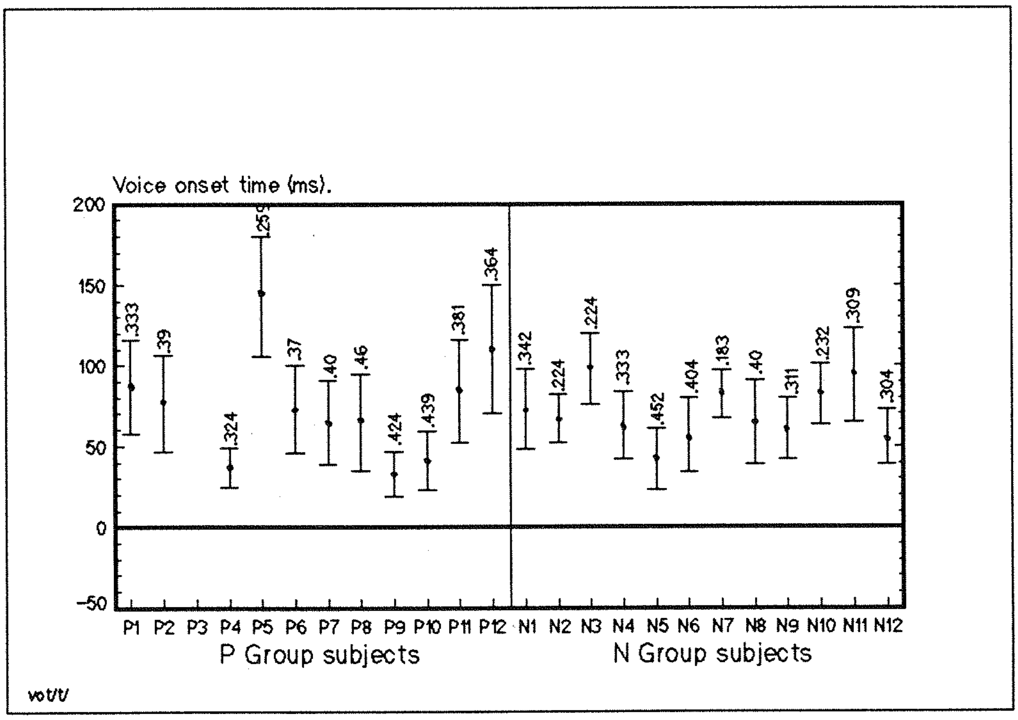

Figure 39. Mean duration and variability of VOT for /t/ in the word 'two' - P & N Groups subjects.

4.3.1.6. Mean duration and variability of voice onset time in the initial consonant in the word 'boys'.

Twenty tokens were excluded from this measure because no burst of energy associated with release of closure was visible on the spectrogram or waveform displays (see section 4.3.1.2 above for full explanation).

Figure 40 displays the distribution of the values of the VOT of the initial consonant in the word 'boys' across all measureable tokens from phonologically delayed child subjects. The figure also displays the distribution of values for this measure in the adult and normal child data, from phase 1, for comparison.
The bar-chart in figure 40 illustrates that the distribution of values was very similar in the two child groups except that the phonologically delayed children produced fewer tokens with long-lag VOTs, above the adult range of values, than the normal child subjects; that is, 6 P Group tokens compared with 16 N Group tokens had VOTs greater than 45 ms.

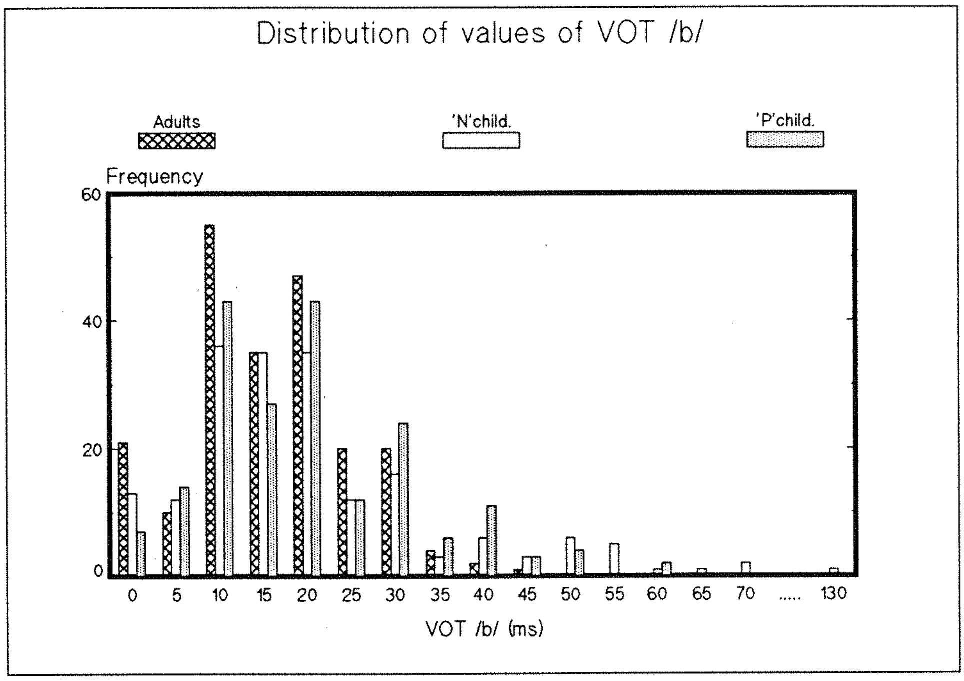

Figure 40. Distribution of VOT values for /b/ in the word 'boys' - A, N & P Groups.

Table 31 shows individual P Group subjects' ranges, means, standard deviations and coefficients of variation on this measure as well as group mean values for mean VOT and variability. The table shows that phonologically delayed child subjects exhibited mean VOTs ranging from 11 - 32 ms with a group mean value of 20 ms; this compares with a range among normally developing child subjects of 7 - 44 ms (group mean 21 ms). A t-test indicated no statistically significant difference between the group means for mean VOT in the two child groups, (p = .889).

As discussed above, in Chapter Three, section 3.3.6.1., the occurrence of zero VOT values for this segment in the data from all three subject group made the coefficient of variation measure inappropriate for the assessment of intra-subject variability, and therefore, although values for 'C' are reported in the usual way in table 31, comparison of intra-subject variability in the three subject groups is made in terms of individual standard deviations in this instance.

Phonologically delayed subjects exhibited individual standard deviations which ranged from 6 - 17 ms (group mean 10 ms). This compared with a range among the normally-developing child group of 4 -24 ms (group mean 12 ms). A t-test showed that this difference between group mean values of individual standard deviation was not statistically significant, (p = .429).

Figure 41 displays individual means bracketed by standard deviation for subjects in the two child groups. Although three N Group subjects show greater variability than any of the P Group subjects, and a wider range of mean VOT values is apparent in the N Group, there is no systematic difference between the two child groups in terms of mean VOT or individual variability.

In summary, these results show that the two child subject groups behaved quite similarly with respect to the VOT of /b/ in the word 'boys'; that is, the two child groups exhibited similar ranges and distributions of values across all tokens, although more extremely long VOTs occurred in the N Group data; there was no significant difference between group means for mean VOT in the two child groups and no significant difference in individual variability between the two child groups.

SUBJECT*	RANGE (ms)	MEAN (ms)	SD (ms)	C (SD/M)
P1	15-50 (35)	32	8	0.25
P2	0-40 (40)	19	10	0.526
P3	5-30 (25)	14	7	0.5
P4	5-50 (45)	21	13	0.619
P5	10-50 (40)	20	10	0.5
P6	0-45 (45)	16	12	0.75
P7(10)	15-40 (25)	30	9	0.3
P8(16)	0-30 (30)	11	10	0.91
P9	0-25 (25)	11	6	0.545
P10(17)	15-40 (25)	24	8	0.333
P11(12)	10-60 (50)	23	14	0.609
P12(15)	5-60 (55)	23	17	0.739

* Number of tokens given in brackets if fewer than 18.

Group mean VOT = 20 ms

Group mean for individual standard deviation = 10ms

Table 31. Duration and variability of VOT for /b/ in the word 'boys' - P Group subjects.

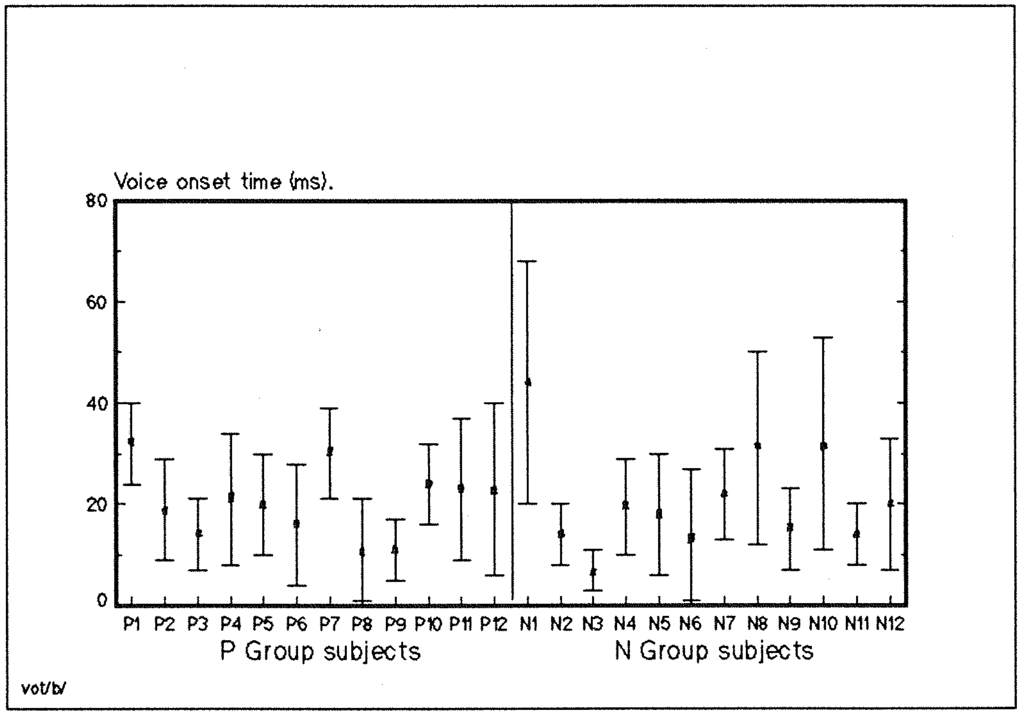

Figure 41. Mean duration and variabilty of VOT for /b/ in the word 'boys' - P & N Group subjects.

4.3.1.7. Mean duration and variability of voice onset time in the initial consonant in the word 'playing'

A total of twelve tokens were excluded from this measure: one token from subject P10 in which a hesitation affected the segment and eleven further tokens were excluded because no burst of energy associated with consonant closure was visible on the spectrogram or waveform displays, (see section 4.3.1.3. above for full details).

Figure 42 displays the distribution of values for this VOT measure across all measureable tokens from phonologically delayed subjects. The figure also displays the distribution of values for this measure in the adult and normal child data, from phase 1, for comparison. The bar-chart, in figure 42, illustrates that the distribution of VOT values in the data from phonologically delayed children was markedly skewed to the left compared with the distribution in the normal child and adult data. That is, the delayed child subjects displayed a strong tendency to produce a plosive consonant with short-lag VOT in this context; 118 P Group tokens of this segment had VOTs of less than 40ms compared with 22 N Group and 21 A Group tokens.

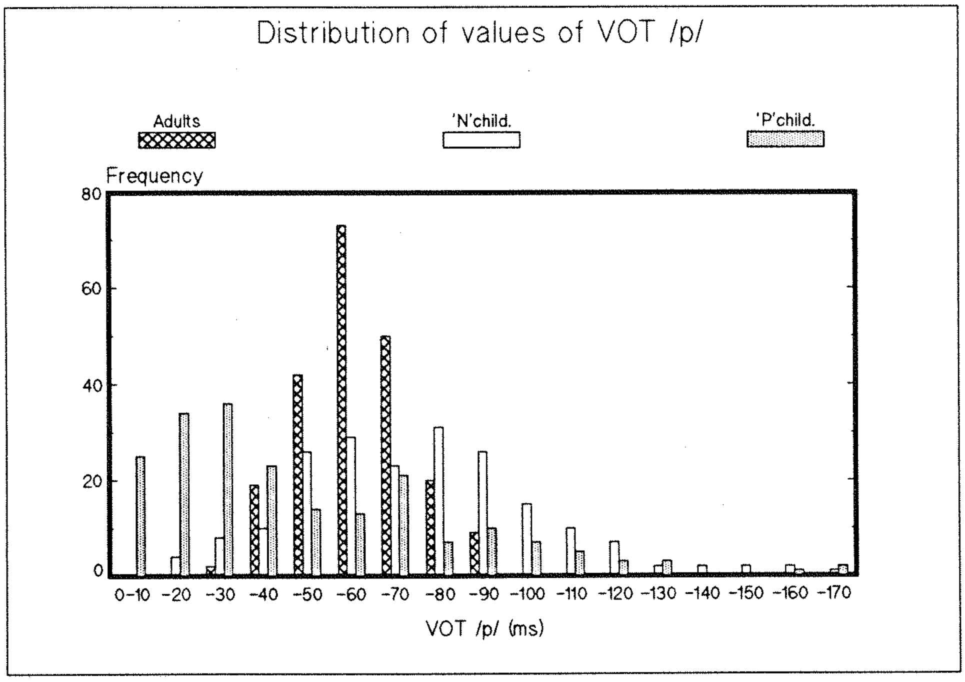

Figure 42. Distribution of VOT values for /p/ in the word 'playing' - A, N & P Group subjects.

Table 32 shows individual P Group subjects' ranges, means, standard deviations and coefficients of variation on this measure and group mean values for mean VOT and variability.
The table shows that mean voice onset times among the phonologically delayed subjects ranged from 10 - 99 ms with a group mean of 47 ms. This compares with a range in the normally-developing child group of 47 - 98 ms (group mean 74 ms). Seven of the phonologically delayed children exhibited mean VOTs for this consonant which were below the range of values found in the normal child data. A t-test confirmed that the difference between group mean values for mean VOT was statistically significant (p = .011) in the direction of shorter duration in the phonologically delayed child group.

Assessment of individual variability on this measure was complicated by the occurrence of zero VOT values in the data from phonologically delayed subjects. As discussed above in relation to the measure of VOT in the initial plosive in the word 'boys', it was decided to compare subjects' temporal variability using individual standard deviation rather than coefficient of variation in such circumstances. Values for the coefficient of variation are reported in the usual way in table 32 and it can be seen that where a subject's data includes zero values the resulting extrememly high value of 'C' is misleading. Phonologically delayed subjects' individual standard deviations ranged from 7 -42 ms (group mean 19 ms) compared with a range in the normally-developing child group of 13 - 38 ms (group mean 23 ms). A t-test showed that the difference between the group means for standard deviation in the two child groups was not statistically significant, (p = .273).
Figure 43 displays individual means bracketed by standard deviation for subjects in the two child groups for ease of comparison and illustrates that there was marked difference in mean VOTs between the two child groups but no systematic difference in intra-subject variability between phonologically delayed and normal child subjects.

SUBJECT*	RANGE (ms)	MEAN (ms)	SD (ms)	C (SD/M)
P1	10-50 (40)	24	9	0.375
P2(17)	10-105 (95)	71	27	0.38
P3	0-25 (25)	10	7	0.7
P4	5-30 (25)	14	7	0.5
P5	50-160 (110)	99	30	0.303
P6	10-70 (60)	33	18	0.545
P7(12)	30-100 (70)	70	25	0.357
P8(17)	5-50 (45)	33	12	0.364
P9	15-70 (55)	36	18	0.5
P10(17)	20-70 (50)	36	12	0.33
P11(16)	35-90 (55)	64	16	0.25
P12(17)	25-170 (145)	76	42	0.553

* Number of tokens given in brackets if fewer than 18.

Group mean VOT = 47 ms

Group mean for individual standard deviation = 19ms

Table 32. Duration and variablity of VOT for /p/ in the word 'playing' - P Group subjects.

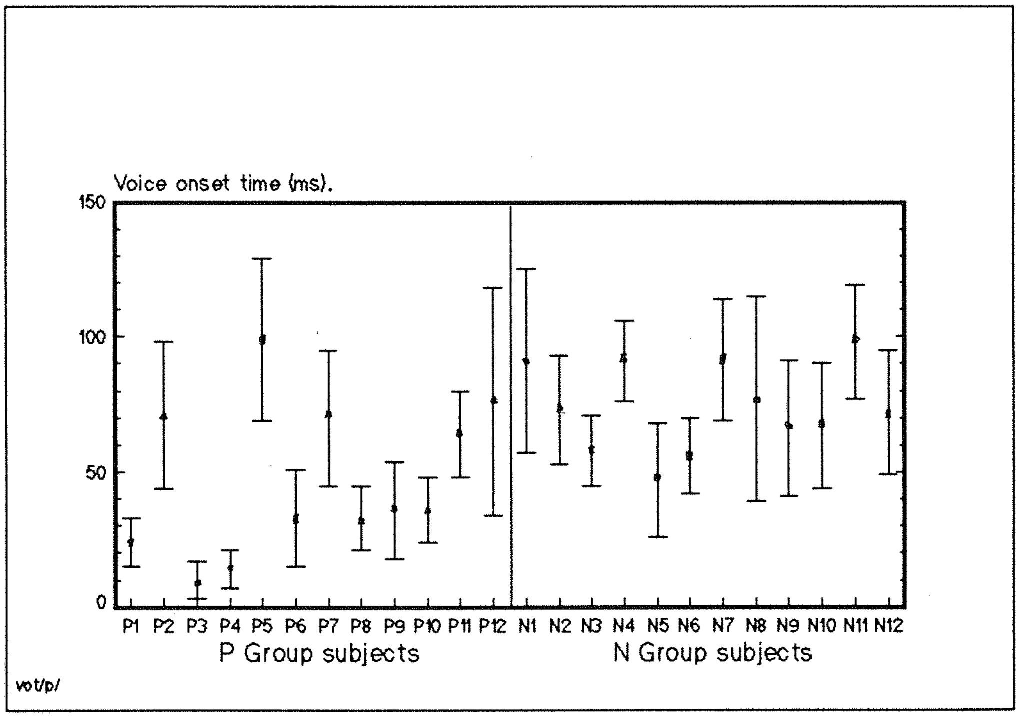

Figure 43. Mean duration and variability of VOT for /p/ in the word 'playing' - P & N Group subjects.

4.3.2. Further analysis of phrase and segment duration measures.

As in the first phase of the investigation, several additional analyses were performed on the temporal acoustic measurements. This section reports the results of these analyses which were undertaken in order to explore further the relationships among the various measures. Where relevant results are related to those from adult and normal child subjects in phase 1.

4.3.2.1. Relationships between mean phrase duration and mean segment durations measures.

In the adult and normal child data it was found that among the segmental durations considered in the investigation, the two consonant closure durations correlated most significantly with subjects' mean phrase durations.
Table 33 displays values for the Pearson Coefficient of Correlation 'r' for relationships between mean phrase duration and each mean segmental duration in the P Group data.

SEGMENT	VALUE OF 'r'	SIGNIFICANCE
Closure /b/	r = .59	not significant
Closure /p/	r = .34	not significant
Vowel in 'boys'	r = .69	1% level
VOT /t/	r = .49	not significant
VOT /b/	r = -.11	not significant
VOT /p/	r = .29	not significant

Table 33. Correlations between mean segment durations and mean phrase durations - P Group subjects.

It can be seen that while positive correlations were found between mean phrase duration and all mean segmental durations except the VOT of the initial plosive /b/ in the word 'boys' (which is of very short duration), the only statistically significant correlation was between mean phrase duration and the mean duration of the vowel in the word 'boys'. In such a small sample little weight can be given to the precise values of the correlation coefficient, but these results give an indication of the relative significance of each of the segmental measures of mean duration in determining individual 'P' Group subjects' mean phrase durations.

4.3.2.2. Relationship between measures of mean duration and measures of temporal variability.

This section firstly examines the relationship between absolute duration and variability for each temporal acoustic measure, and secondly the data are analysed to determine whether any relationship is apparent between individual phonologically delayed subjects' mean phrase duration (speed of utterance) and overall level of temporal variability.
It will be recalled that in the previous experiment (see Chapter Three, section 3.3.2.3.), no consistent relationship between absolute durations and temporal variability was apparent in the adult data, but in the N Group data there was some evidence of negative relationship between mean duration and variability of duration on some measures, and evidence of a negative correlation between rank for mean phrase duration and mean rank for measures of temporal variability.

Figures 44 - 48, on the following pages, plot individual P Group subjects' mean durations against durational variability for the measures of phrase duration, the two consonant closure durations, the vowel duration and one VOT measure. The VOT measures for the initial plosives in the words 'boys' and 'playing' have not been included here because the occurrence of zero VOT values necessitated the use of a method of estimating variability which was not consistent with other measures. The figures also include plots of the same relationships for A and N Group data, obtained in phase 1, for comparison.

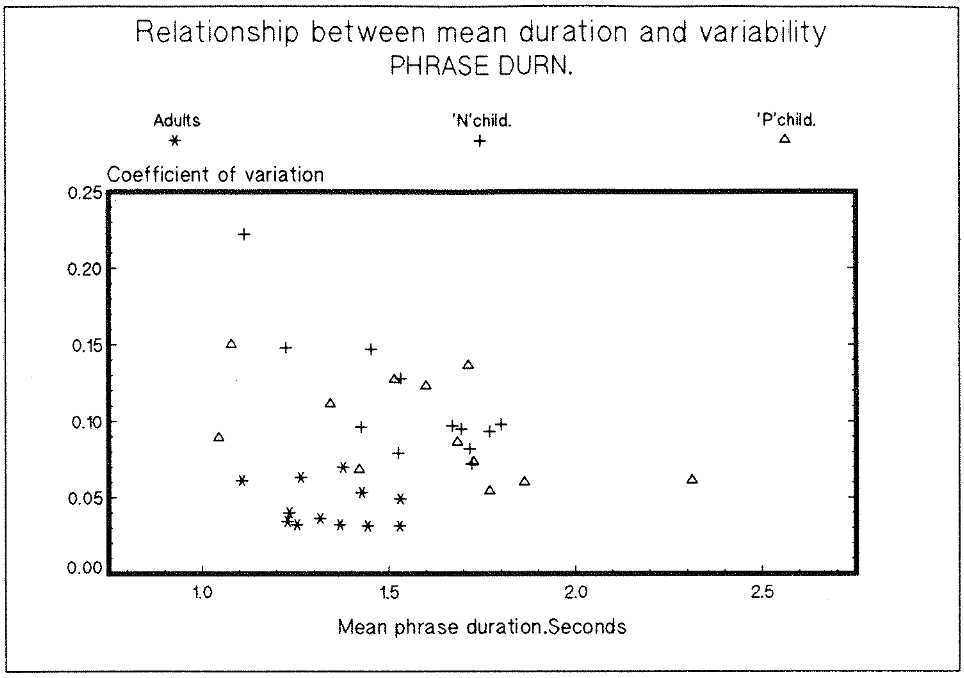

Figure 44 - Scatterplot of the relationship between mean duration and variability for the experimental phrase - A, N & P Groups.

The distribution of points on the scatterplot for P Group subjects in figure 44 suggests some degree of negative correlation between mean duration and variability for this measure. This is confirmed by a value for the Pearson Coefficient of Correlation 'r' of -.525, although this value does not reach statistical significance at the 1% level.

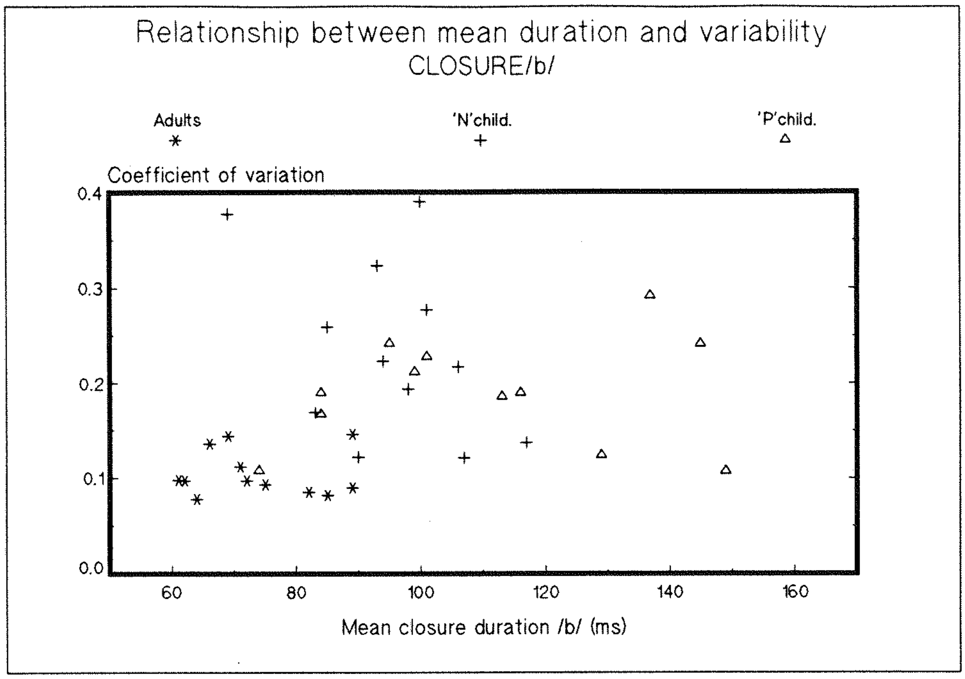

Figure 45. Scatterplot of the relationship between mean duration and variability of duration of closure for /b/ in the word 'boys'- A, N & P Group subjects.

The distribution of points in this figure does not suggest any linear relationship, which is confirmed by a very small value for the Pearson Coefficient of Correlation 'r' of .138.

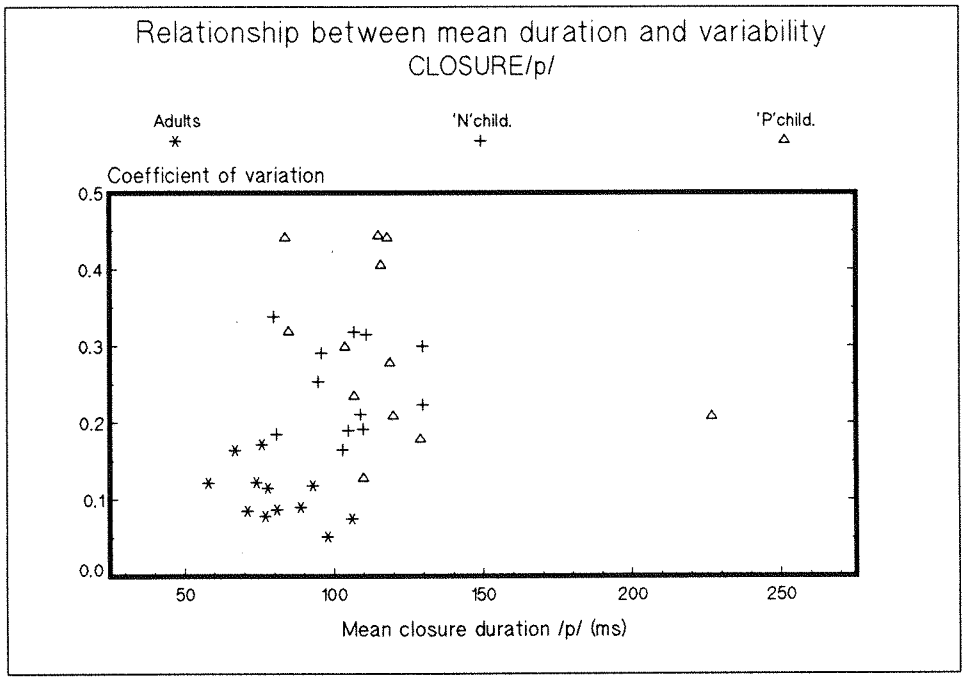

Figure 46. Scatterplot of the relationship between mean duration and variability of duration of closure for /p/ in the word 'playing' - A, N & P Groups subjects.

The distribution of points for P Group subjects for this closure duration measure, shown in figure 46, do not indicate any overall linear relationship between mean duration and degree of variability. The value of the Pearson Coefficient of Correlation 'r' was found to be -.345, which, although not statistically significant at the 1% level, does suggest negative correlation. However, when the scatterplot points are examined it can be seen that this value of 'r' is heavily dependent on one outlying value for mean closure duration (Subject P1).

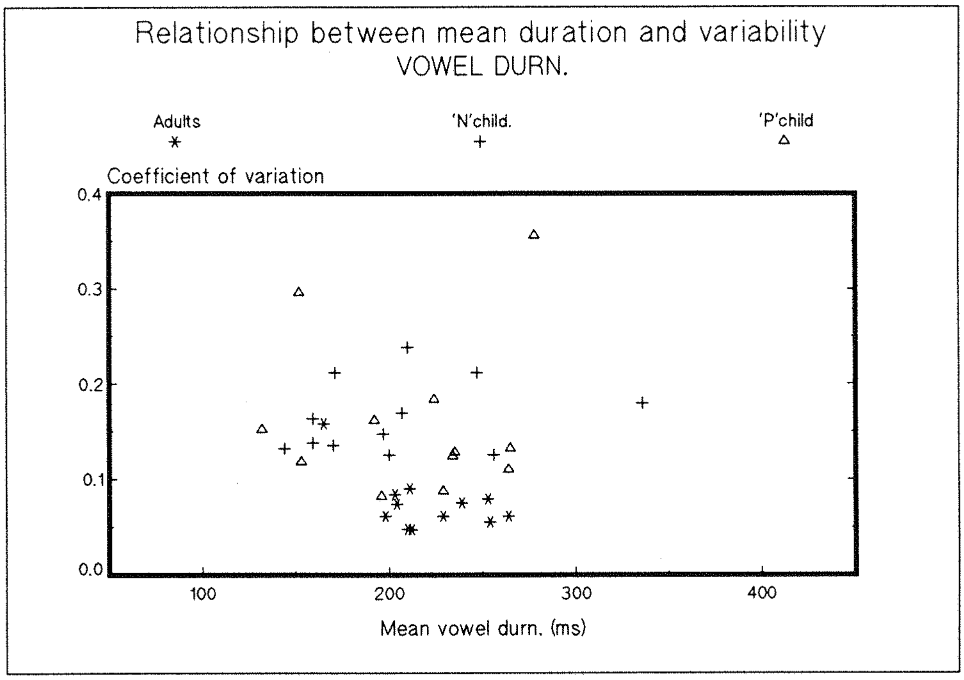

Figure 47. Scatterplot of the relationship between mean duration and variability of duration for the vowel in the word 'boys' - A, N and P Group subjects.

Figure 47 shows no linear relationship between mean vowel duration and variability of vowel duration for the P Group subjects and this is confirmed by a very small value for the Pearson Coefficient of Correlation 'r' of .056.

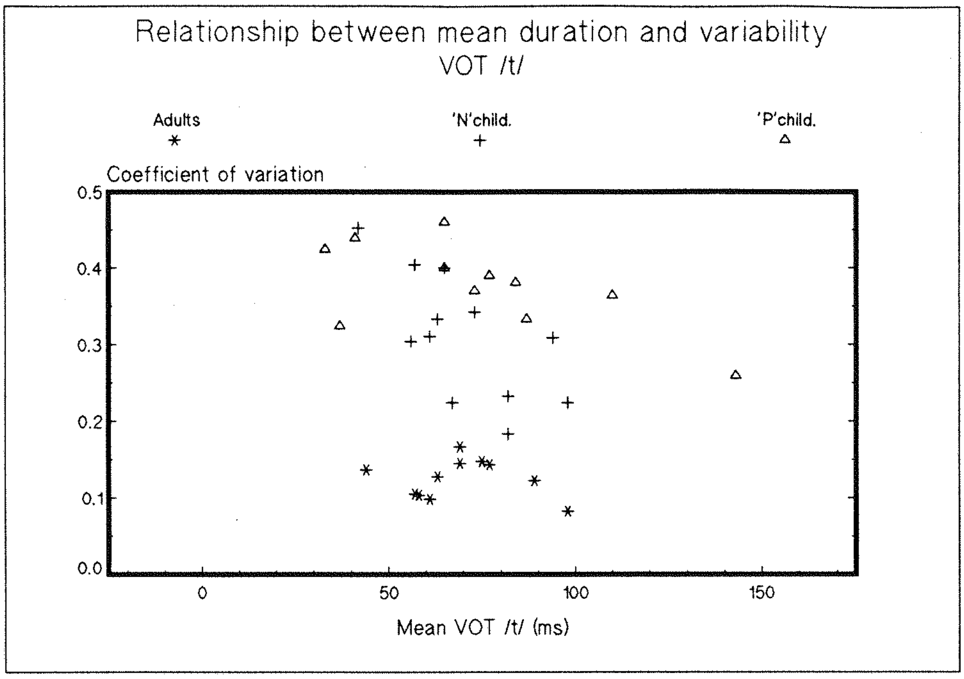

Figure 48. Scatterplot of the relationship between mean duration and variability of VOT for /t/ in the word 'two' - A, N & P Group subjects.

The distribution of points on the scattergram in figure 48 indicates some degree of negative correlation between mean VOT and variability of VOT for P Group subjects. This is confirmed by a negative value of -.582 for the Pearson Coefficient of Correlation, although this value of 'r' does not reach statistical significance at the 1% level.

Thus the results of this investigation of relationship between mean duration and variability in phrase and segment durations in the P Group data suggest that a weak (but not statistically significant) tendency exists for short mean durations to be associated with relatively high levels of variability on the measures of phrase duration, closure duration /p/ and VOT /t/; while the other two segmental measures considered showed no linear relationship between mean duration and durational variability. It will be recalled that in the A Group data (phasel) there was no apparent relationship between absolute durations and durational variability, while in the N Group data the evidence suggested a negative relationship between absolute durations and temporal variability with statistically significant correlations for phrase duarion and VOT of /t/ in the word 'two'. There is therefore considerable similarity between the results of this analysis in the two child subject groups.

Table 34 lists the phonologically delayed subjects by rank (within group) for mean phrase duration and shows each subject's rank (within group) for coefficient of variation 'C' for the measures of phrase duration, the two consonant closure durations, the vowel duration measure and one VOT measure, (the VOT measures for the initial plosives in the words 'boys' and 'playing' have not been included for the reasons given above). The extreme right hand column of the table gives each subject's mean rank within group across these five measures of temporal variability.

Subj.		Rank for coeff. of variation 'C'					
	Rank for mean phr.durn.	Phr.	Clos./b/	Clos./p/	Vowel.	VOT/t/	Mean Rank 'C'
P8	1	7	6	8	8	11	8
P7	2	12	2	10	4	8	7.2
P11	3	8	8	7	10	6	7.8
P3	4	4	4	5	2	*	3.8
P10	5	10	12	9	11	10	10.4
P4	6	9	6	10	12	2	7.8
P1	7	6	1	3	1	3	2.8
P12	8	11	11	12	9	4	9.4
P2	9	5	10	6	5	7	6.6
P9	10	1	5	2	3	9	4
P6	11	2	9	4	6	5	5.2
P5	12	3	3	1	7	1	3

* A process of glottal replacement occurred in all tokens from subject P3, and therefore mean rank for 'C' is calculated over only 4 measures.

Table 34. Relationship between rank for mean phrase duration and average rank across five measures of temporal variability - P Group subjects.

Figure 49 plots each subject's rank for mean phrase duration against mean rank for temporal variability over these five measures.

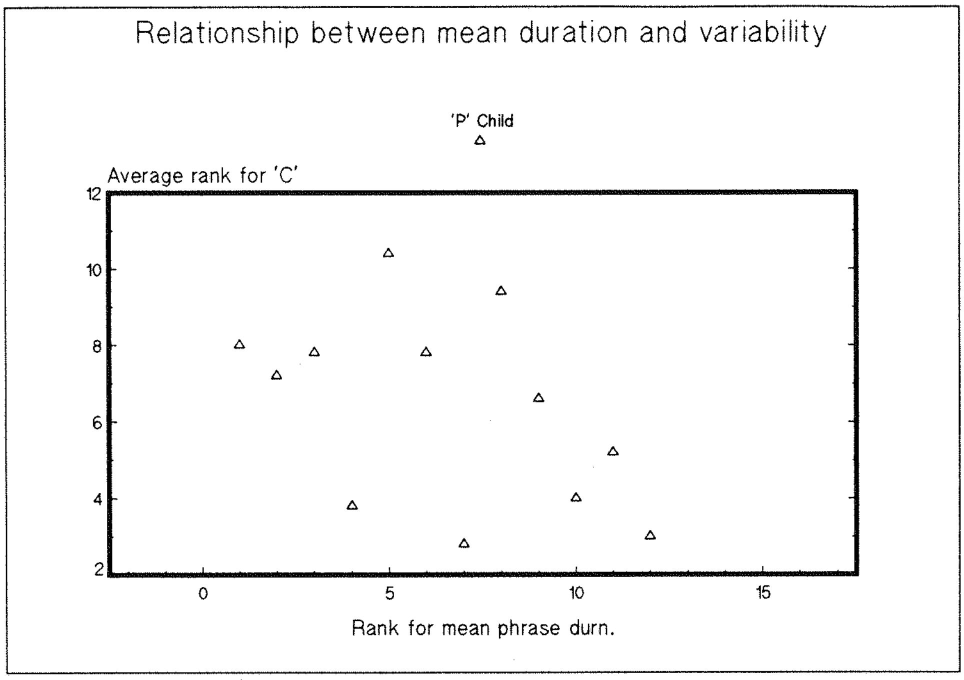

Figure 49. Scatterplot of the relationship between rank for mean phrase duration and average rank across five measures of variability - P Group subjects.

Table 34 indicates that relationship between mean duration and temporal variability is not consistent throughout the P Group data, with subjects who have mid-group rankings for mean phrase duration showing widely differing mean ranks for temporal variability. However, when ranks for coefficient of variation 'C' are examined for subjects at the extremes of the ranking for mean phrase duration there is evidence to suggest that subjects who take the longest mean time to produce the phrase tend to be more consistent in their timing than the subjects who take the shortest mean time to say the phrase. The scatterplot in figure 49 confirms this suggestion of a weak general trend towards negative relationship between rank for mean phrase duration and mean rank for temporal variability. It will be recalled that a similar, but somewhat more consistent trend was found, in phase 1 of the investigation, in the normal child data. That is, there is a tendency in both child subject groups for subjects who take the longest mean time to say the phrase to achieve more consistent speech timing than other subjects in their group.

4.3.3. Summary of temporal acoustic measures.

This section summarizes the results of the measures of phrase and segment durations and temporal variability in the phonologically delayed subjects' data in relation to the results of the first phase of the investigation.

4.3.3.1. Absolute durations.

When distributions of durational values for each measure were examined across all P and N subjects' tokens, only the measure of VOT in the initial plosive in the word 'playing' showed a marked difference between the two groups. There was a general tendency on the other measures for more P Group than N Group tokens to fall at the extremes of the ranges of distribution.
Phonologically delayed subjects exhibited wider ranges of mean durations than the normal child subjects on all measures except the vowel duration measure and the VOT measure for the initial plosive in the word 'boys'. That is, there were in general greater inter-subject differences among the delayed child subjects than among the normal child subjects on measures of mean duration.
Comparison of group mean values for mean durations resulted in significant difference between the two child groups only on the measure of VOT in the initial plosive in the word 'playing' (see table 35, below). That is, for the measure of mean VOT in the voiced plosive target /b/ in the word 'boys' there was negligible difference between group means in the two child groups; on the measure of VOT for the voiceless plosive target /p/ in the word 'playing' there was a significant difference between the child group with significantly shorter mean VOTs occurring in the P Group; and on the remaining segmental measures and the phrase duration measure, group means were greater in the P Group than in the N Group, but these differences between group means did not reach statistical significance. Group mean differences came nearest to statistical significance for the two measures of consonant closure duration. It will be recalled that in the first phase of the investigation (see Chapter Three, section 3.3.) a general trend towards longer mean duration in the normal child group compared to the adult group was found, with the two consonant closure durations giving the most statistically significant results.

Mean durational measure.	P Grp. mean	N Grp. mean	Value of 'p' (t-test)
Phrase	1589ms	1554ms	.768
Closure /b/	111ms	95ms	.079
Closure /p/	120ms	105ms	.218
Vowel in 'boys'	213ms	205ms	.703
VOT /t/	74ms	70ms	.713
VOT /b/	20ms	21ms	.889
VOT /p/	47ms	74ms	.011

Table 35. Significance levels of differences between group mean durational measures - P & N Groups.

4.3.3.2. Temporal variability.

Differences between N and P Group means for individual variability were not statistically significant with the exception of the measure of VOT for /t/ which resulted in a difference significant at the 5% level.

Table 36 summarizes group mean values and significance levels of differences between group means for individual variability on each measure.

Measure	P Grp. mean	N Grp. mean	Value of 'p' (t-test)
Phrase	'C' = .095	'C' = .133	.254
Closure /b/	'C' = .19	'C' = .234	.176
Closure /p/	'C' = .289	'C' = .248	.189
Vowel in 'boys'	'C' = .161	'C' = .164	.894
VOT /t/	'C' = .377	'C' = .31	.035
VOT /b/	S.D. = 10ms	S.D. = 12ms	.429
VOT /p/	S.D. = 19ms	S.D. = 23ms	.273

Table 36. Significance levels of differences between group means for temporal variability measures - P & N Groups

4.3.3.3. Additional analyses of temporal acoustic measures.

Additional analysis examined the relationship between absolute duration and variability of duration for the phrase duration measure and for four segmental measures. On two segmental measures no linear relationship was apparent, while on the phrase duration and two segmental measures non-significant negative correlations were found. In no case was a positive relationship between mean duration and durational variability found.

When P Group subjects' ranks for mean phrase duration were plotted against mean rank for coefficient of variation across five measures, it was found that the longest mean phrase durations tended to be associated with low levels of temporal variablity and the shortest mean phrase durations tended to be associated with high levels of temporal variability.
Similar relationships between absolute durations and temporal variability had been found in the normal child data in the first phase of the investigation.

Thus, in summary, temporal acoustic analysis of the data from the phonologically delayed child subject group has shown;
(i) that, in general, group means for measures of mean duration tended to be longer in the delayed child group, but the differences between the two child groups were not statistically significant,

(ii) that the measure of VOT in the initial plosive in the word 'playing' was an exception to this general trend, in that difference between the two child groups was statistically significant and in the direction of shorter durations in the P Group,
(iii) that measures of intra-subject variability, with the marginal exception of the measure of VOT for /t/, did not distinguish between the two child subject groups,
(iv) that similar relationships between mean durations and durational variability existed in the two child subject groups.

4.3.3.4. Comparison of A Group and P Group subjects on temporal acoustic measures.

Section 4.3. has focused on comparison of the results of temporal acoustic measures in the phonologically delayed and normal child groups. Section 3.3., in the previous chapter, focused on differences between the adult and normal child subject groups. For the sake of completeness this section reports the significance levels of the differences between the adult and phonologically delayed child groups on these same measures.

Table 36A shows the significance levels of the differences between the A and P Group mean values on each mean durational measure.

Mean durational	**A Grp. mean**	**P Grp. mean**	**Value of 'p' (t-test)**
Phrase	1340ms	1589ms	$p = .035$
Closure /b/	74ms	111ms	$p < .001$
Closure /p/	81ms	120ms	$p < .01$
Vowel ('boys')	220ms	213ms	not sig.
VOT /t/	68ms	74ms	not sig.
VOT /b/	16ms	20ms	not sig.
VOT /p/	60ms	47ms	not sig.

Table 36A. Significance levels of differences between group mean durational measures - A and P Groups.

The table shows that the pattern of difference is similar to that for the A and N Group comparisons reported in Chapter Three (section

3.3.3.1.), with the exception of the measure of VOT for /p/ in the word 'playing' for which the difference between A an P Groups did not reach statistical significance when a t-test was applied. This finding in relation to the VOT of /p/ is consistent with the finding of a significant difference between the N and P Groups on this measure in the direction of shorter mean VOTs in the P Group. It can also be seen from table 36A that the level of significance of the difference between A and P Groups on the measure of mean phrase duration is lower than for the A and N Group comparison (see table 20 in section 3.3.3.1.). This finding is consistent with the occurrence, in the P Group data, of individual mean phrase durations which fell below the adult group range of values.

Table 36B shows statistical significance levels of the differences between A and P group mean values on measures of temporal variability.

Measure	**A Grp. mean**	**P Grp. mean**	**Value of 'p' (t-test)**
Phrase	C = .044	C = .095	p < .001
Closure /b/	C = .015	C = .19	p < .001
Closure /p/	C = .106	C = .289	p < .001
Vowel ('boys')	C = .074	C = .161	p < .01
VOT /t/	C = .118	C = .377	p < .001
VOT /b/	*SD = 6ms	SD = 10ms	p = .001
VOT /p/	SD = 9ms	SD = 19ms	p = .01

* For explanation of the use of Standard Deviations see section 3.3.1.6.

Table 36B. Significance levels of differences between group means for temporal variablity - A and P Groups.

It can be seen that the pattern of difference is similar to that found between the A and N Groups reported in Chapter Three. That is, there were statistically significant differences in intra-subject temporal variablity on all measures between the adult and phonologically delayed child subjects.

4.4. RESULTS OF PERCEPTUAL (AUDITORY) ANALYSIS

This section examines the phonological form of the data from phonologically delayed child subjects. The number of perceptually distinct segments in each token is counted (as for the adult and normal child data in phase 1) and the occurrence of reduced forms analysed across all subjects in the group and for each individual subject. Results from the first phase of the investigation are, in many of the tables and figures, repeated for ease of comparison, and such comparisons are made with the phonological form of the adult and normal child data throughout the section.

The P Group data consisted of 216 tokens of the phrase 'two wee boys are playing in the'.
In Appendix 3B the analysis sheets for each phonologically delayed child subject can be examined. These analysis sheets show realisations of each segment of the phrase in each token, in relation to the usual forms found in the adult data in phase 1 of the investigation. Structural simplifications (deleted segments) are marked /∅/ and segments which were adult-like in form are not transcribed. The analysis sheets include each P Group subject's mean phrase duration and rank within group for mean phrase duration; and the phrase duration (to the nearest 0.1 of a second), number of segments and number of syllables is displayed for each token of the phrase.

4.4.1. Number of speech segments

Two hesitant tokens, from subject P10, which involved repetition of segments were excluded from this measure. The number of perceptually distinct segments in all remaining tokens (214) of the phrase was counted using the same criteria as in the first part of the investigation. The bar-chart in figure 50 displays the number of segments in tokens from phonologically delayed subjects compared with the tokens from the normal child subjects in phase 1. The figure shows marked contrast between the data from the two groups. That is, whereas 110 N Group tokens (51.4%) consisted of 16, 17 or 18 segments, none of the P Group tokens consisted of more than 15 segments. It can also be seen from the bar-chart that many more P Group tokens than N Group tokens were severely reduced in structure.

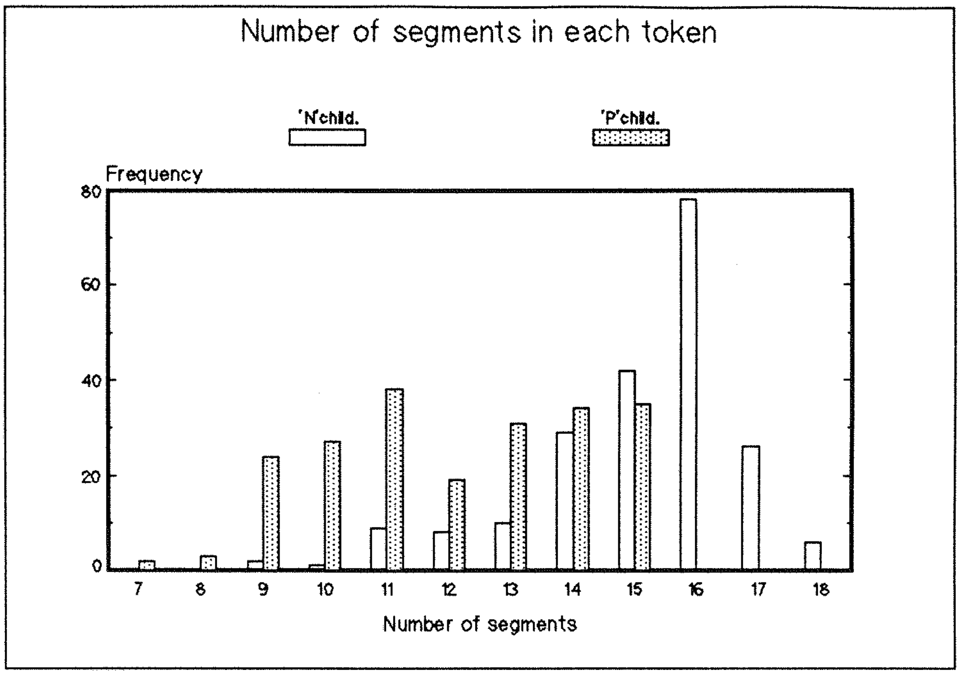

Figure 50. Bar-chart showing number of segments in tokens of the experimental phrase spoken by P & N Group subjects.

4.4.2. Reduced forms and word omissions.

Analysis of the P Group tokens showed that none could be regarded as adult-like in phonological form using the criteria established in Chapter Three, section 3.4.2.2.. That is, all tokens from phonologically delayed child subjects exhibited non-adult-like structural reductions and/or segment realisations. This finding contrasts with the 24.8% of N Group tokens which were adult-like in phonological form.
Reduced forms and word omissions affecting each word of the target utterance in the P Group data are described below and compared to those found in the adult and normal child data in phase 1:

Phonologically delayed subjects were less likely than the normally-developing child subjects to produce the initial segment of the phrase (/t/ in the word 'two') in an adult-like form. That is; in the P Group data, this segment was realised as a voiceless, aspirated, alveolar plosive [t^h] in only 146 tokens compared with 204 N Group tokens.

In 49 of the remaining P Group tokens the segment was heard as a voiced, unaspirated alveolar plosive [d], and in these tokens this perceptually based judgement was confirmed by spectrographic and wave-form evidence showing short voice onset times; in contrast, there were only 5 such examples among N Group tokens.
A further 19 P Group tokens exhibited realisations of the word 'two' in which the initial consonant was deleted and there was glottal closure prior to the vowel; subject P3 exhibited this glottal replacement in all 18 of his tokens and there was one further example from subject P4. This form of the word 'two' occurred only in the P group data. There was also a single example in the P Group data of an affricated release of the stop, [$t^{ɬ}$]. In three tokens from Subject P12 the initial segment of the target phrase was preceded by an additional segment. One was perceived as a glottal closure followed by a neutral vowel [ʔə] and the other two as lateral clicks [ʖ]. In one token realisation of the initial segment could not be analysed because of noise on the recording.

Phonologically delayed and normally-developing child subjects behaved quite similarly with respect to their realisations of the vowel in the word 'two'. There were 193 P Group tokens in which this segment was realised as a close, back, rounded vowel [u] or as a more fronted vowel [ʉ] which were the forms found in all the adult tokens and in 205 of the N Group tokens.
There were 12 examples among the P Group tokens of reduced realisations of this vowel: [ə], [ɪ] or [ʉ̆], compared with 8 such examples in the N Group data; and 3 examples of prolonged realisations of the vowel, [u:], compared with 1 example among the N Group tokens.
In seven P Group tokens a discontinuity of phonation was perceived within the vowel. In some cases this was accompanied by spectrographic evidence of a decrease in energy in the vowel formants.

The next word of the experimental phrase ('wee') was omitted from 38 of the tokens spoken by phonologically delayed child subjects. This compares with only 5 instances of omission of the word in the N Group data.
In 29 P Group tokens the word 'little' was substituted for the word 'wee'. (As reported in the previous chapter, this substitution was

also found in 24 N Group tokens.)
In 113 of the P Group tokens which included the word 'wee', the initial consonant segment was realised, as in the adult data, as a labial-velar approximant [w], compared with 181 such adult-like realisations in the N Group data.
In a further 29 P Group tokens the consonant segment was deleted, compared with only 2 such examples in the N Group data.
There were 5 examples of substitutions of another consonant segment in the P Group data; [d] (2tokens), [v] (1 token), [b] (1 token), [ç] (1 token), compared with 2 examples in the N Group data.
There were 10 examples in the P Group data in which the vowel in the word 'wee' was reduced to [ə] or [ɪ]: 10 such examples also occurred in the 'N' Group data.

The initial consonant segment of the word 'boys' was represented in all 216 P Group tokens of the phrase and it was found that the two groups of child subjects exhibited similar forms and frequencies of non-adult-like realisations of the segment. That is, in 193 of the P Group tokens the segment was realised as a voiced, bilabial plosive [b] such as was found in all but one of the adult tokens, and in 184 of the N Group tokens; in 22 P Group tokens the segment was realised with extremely lax articulatory closure or with absence of closure which resulted in segments which were heard either as lax plosives [b̞] , as fricatives [β̞]; [ɸ] or [ʋ] or as continuants [w] or [ʋ̞]. All these forms were found to occur with similar frequency in the data from the normally-developing child subjects.
There were no examples in the P Group data, comparable to the 3 N Group examples of aspirated, voiceless, bilabial plosives in this context.
The vowel in the word 'boys' was represented in all of the 216 P Group tokens of the phrase and it was found that the two child subject groups behaved quite similarly with respect to its realisation, except that there were rather more P Group tokens in which the vowel in 'boys' was reduced to a monophthong.
In 202 P Group tokens the vowel in the word 'boys' was realised as a diphthong and, as in the adult and normal child data, the most usual form of the diphthong was [ɔe] which is usual in the local speech community. As in A and N Group data, the P Group tokens included examples in which the form of the diphthong was
[ɔɪ] or [ɔi]; all of these are regarded as adult-like forms.

In 11 P Group tokens this vowel segment was realised as a monophthong [ɔ] (compared with only 2 examples in the N Group data).
In 2 P Group tokens a discontinuity of phonation within the vowel was observed. In one of these, token 13 from subject P11, there was spectrographic evidence of a fall in energy in all formants associated with this perceived discontinuity.

Phonologically delayed subjects were much less likely than N Group subjects to produce an adult-like final consonant segment in the word 'boys'; that is, there were 96 P Group tokens in which the segment was perceived as an adult-like, voiced alveolar fricative, compared with 186 examples among N Group tokens.
The segment was deleted from 63 tokens from phonologically delayed subjects compared with only 16 instances of deletion in the N Group data.
The delayed child subjects were more likely than the normal child subjects to realise this segment as a homorganic stop [d]; that is, there were 39 such examples in the P Group data compared with only 3 among N Group tokens.
There were also more examples in the P Group data of inaccurate articulatory placement in the realisations of this fricative segment. That is, 19 P Group tokens exhibited fronted articulatory placements in which the segment was heard as [v], and 6 tokens in which there was slightly retracted placement [z̠]. In comparison, in the N Group data only 9 examples of non-adult-like fricative placement occurred and these all involved retracted rather than fronted placements.

Realisations of the next word 'are' in the phonologically delayed subjects' tokens were very similar to those found in the normal child data. The word 'are' was omitted from a large proportion of tokens in the data from both the child groups, (86 P Group tokens and 89 N Group tokens). Where the word was represented, child subjects in both groups were more likely to produce the word as a full form [a] or [aṛ] and less likely to exhibit the adult-like reduction to [ə], [ɚ], [ʌ] or [ʌ˞]; that is, there were 50 P Group examples and 47 N Group examples in which the form [a] or [â˞] occurred, compared with 21 examples in the adult data.

In the next word 'playing', the phonologically delayed child subjects were much less likely than the normal child subjects to produce a disyllabic structure; that is, there were 20 P Group examples of disyllabic realisation of the word 'playing', compared with 75 N Group examples.

The initial consonant cluster in the word 'playing' was judged to be adult-like in form in only 13 of the tokens from phonologically delayed child subjects. This compared with 184 adult-like realisations of the cluster in the N Group data. In a further 24 P Group tokens the cluster consisted of 2 elements but was not adult-like in form, that is, it was realised as [bl] (1 token), [pw] (4 tokens) or [bw] (19 tokens); similar realisations occurred in 17 N Group tokens. In the remaining 179 P Group tokens the cluster was reduced to one element only; [pʰ], [p=], [pᶲ] (102 tokens); [f] (4 tokens); [v] (5 tokens); [ɸ] (1 token); [β̞] (1 token) and [b] (66 tokens). Such reductions occurred in only 13 of the N Group tokens. It can also be seen from the foregoing analysis that the phonologically delayed subjects favoured voiced realisations of this consonant cluster compared with the normal child group; that is, there were 92 'P' Group tokens in which the realisation of this target cluster was entirely voiced compared with only 4 such examples in the 'N' data.

There were only 9 tokens in the P Group data in which the final consonant segment of the word 'playing' was realised as a velar nasal /ŋ/, compared with 78 adult-like realisations found in the normal child data. Conversely, there were more tokens in the P Group data in which this segment was realised as an alveolar nasal [n]; 140 compared with 96 in the N Group data.
Phonologically delayed subjects were also more likely to delete this segment; that is in 65 tokens compared with 39 in the N Group data. Two further P Group tokens exhibited a stop consonant [d] or [d̚] in this context.

The word 'in' was omitted from 24 of the P Group tokens of the phrase compared with one omission in the N Group data.
Of the remaining tokens, 136 consisted of 2 segments, a vowel and an alveolar nasal, compared with 186 such examples in the 'N' Group data. The vowel was adult-like in the majority of these with the exception of 1 example of [ən], 1 of [ɪ̃n] and 8 of [ʌ̃n]. In a further 56 P Group tokens the nasal segment was deleted.

The final word of the phrase, 'the', was omitted from 44 of the tokens spoken by phonologically delayed subjects, compared with only 13 such omissions among N Group tokens.
Only 2 P Group tokens were found to exhibit realisations of this segment which resembled the usual adult form as described in Chapter Three, Section 3.4.1.; that is, in which the segment was perceived as an interdental or dental fricative. This contrasts with 87 such adult-like examples among the tokens from the normally-developing child subjects.
There were similar numbers of tokens in the data from the two child groups in which the initial segment in the word 'two' was realised as a voiced alveolar plosive [d]; that is, 18 P Group tokens (all from one subject) and 23 N group tokens.
The phonologically delayed subjects were more likely than the non-delayed child subjects to omit the initial segment, that is, to realise the word 'the' as a vowel only, [ə]. This form of the word was found in 150 P Group tokens compared with 91 N Group tokens. In 18 of these 150 tokens, all from subject P12, a glottal stop preceeded the vowel, that is, 'the' -> [ʔə].

It was pointed out in the previous chapter (section 3.4.2.) that word by word analysis does not highlight the extent to which the section 'playing in the' was reduced in structure in some child subjects' data. In the N Group data it was found that in a majority of tokens this section of the phrase consisted of either 4 syllables or of 3 syllables with reduction of the word 'playing' to a monosyllable [pleŋ] or [plen], and 73 N Group tokens exhibited further structural reduction. The phonologically delayed subjects were found to be more likely to reduce the structure of this section of the target utterance than the normal child speakers. That is, in the P Group data there were 50 tokens in which a three syllable structure was apparent but in which deletion of consonant segments occurred; for example [pʰen.ɪ.ə],[ben.ɪ.ə], [pʰe.ɪn.də], and a further 68 tokens in which only 2 syllables were realised; for example [ben.ɪ], [pʰe.nə].

The individual subject analyses of the phonological form of the P Group data (see Appendix 3B) show, as in the N Group data, considerable inter-subject differences within the phonologically delayed child group. Some P Group subjects display relatively few

structural reductions in their tokens; for example subject P5 exhibits 36 segment deletions, subject P2 exhibits 49, subject P9 exhibits 52 and subject P6 exhibits 54 segment deletions. Other P Group subjects show a much greater tendency to reduce the structure of the target utterance; for example subject P7 deletes a total of 129 segments over 18 tokens, subject P11 exhibits 145 segment deletions and subject P8 deletes a total of 150 segments.
There are also quite marked inter-subject differences in the numbers of non-adult-like segment realisations found in subjects' data. For example subject P5 exhibits 49 non-adult-like segments affecting 4 different segments of the target phrase, while subject P7 exhibits 57 non-adult-like segment realisations which affect 9 different segments.

When individual analyses of phonological form in P Group subjects are compared with the analyses of the N subjects' data it is apparent that while in some phonologically delayed subjects' data a majority of non-adult-like reduced forms are variable in occurrence, as is the case in the N data, other P Group subjects (for example P5 and P3) are more consistent in their use of reduced forms; and in the P Group data as a whole, compared with the N data as a whole, it is more common to find particular reduced forms occurring in all the tokens produced by an individual subject.

4.4.3. Summary of the phonological characteristics of the P Group data in relation to the N Group data.

The phonological form of the data from phonologically delayed child subjects differed from the normal child data with respect to both the number of deletions and the number of non-adult-like segment realisations. That is, the delayed subjects were more likely to reduce the structure of the target utterance by deleting unstressed words; they were more likely to reduce the structure of the target utterance by deleting segments; and they were more likely to exhibit non-adult-like realisations of segments.These findings are summarised in tables 37 - 39.

Table 37 summarises the instances of word omissions in the phonologically delayed children's data and compares it with the adult and normal child data from phase 1 of the investigation.

WORD.	**A GRP.**	**N GRP.**	**P GRP.**
two	0	0	0
wee	0	5	38
boys	0	0	0
are	1	89	86
playing	0	0	0
in	0	1	24
the	2	13	44

Table 37. Occurrence of word omissions - A, N & P Groups

Table 38 summarises instances of segment deletion across the P Group subjects and compares them with the adult and normal child subjects.

SEGMENT	A GRP.	N GRP.	P GRP.
/t/	0	0	19 *
/u/	0	0	0
/w/	0	2	29
/i/	0	0	0
/b/	0	0	0
/ɔe/	0	0	0
/z/	0	16	63
/əʳ/	-	-	-
/p/	0	0	0
/l/	0	13	179
/e/	0	0	0
/ɪ/	15	139	196
/ŋ/	0	39	65
/ɪ̶/	0	15	0
/n/	0	12	56
/ð/	18	91	150
/ə/	0	0	0

* initial plosive segment deleted and replaced by glottal release of the following vowel.

Table 38. Occurrence of segment deletions - A, N & P Groups

Table 39 summarises the occurrence of non-adult-like forms in the data from the phonologically delayed child group and compares it with the data from the normal child group in phase 1 of the investigation. The occurrence figures given in table 39 include all instances of phonemic substitution, lax, undershot, imprecise articulation as well as excessively short or prolonged realisations of segments.

SEGMENT	N GROUP.	P GROUP.
/t/	5	49
/u/	9	22
/w/	2	5
/i/	10	10
/b/	30	22
/æ/	7	13
/z/	12	75
/ɚ/	-	-
/pl/	30	203
/e/	25	21
/ɪ/	1	6
/ŋ/	96	142
/ɪ/	11	42
/n/	0	0
/ɝ/	23	18
/ə/	0	18

Table 39. Occurrence of non-adult-like segment realisations: P & N Groups

Although the data from the two child groups differed quite markedly on these quantitative analyses, the two sets of data were quite similar with respect to the kind of non-adult-like phonological forms which occurred. The analysis given in the previous section and summarised in tables 37 -39 shows that the same words and segments tended to be affected by deletions and non-adult-like realisations in both the N and P Group's data and that in general the particular forms of the non-adult-like realisations were similar in the data from the two child groups.

That is, the only non-adult-like forms found in the P Group data which had not already been encountered in phase 1 in the N Group data were the following:

(i) deletion of the initial segment of the phrase, /t/ , with glottal release of the following vowel; 19 examples, 18 from subject P3 and 1 from subject P4;

(ii) fronting of the final segment in the word 'boys', /z/ -> [v], 18 examples, 2 from subject P2 and 16 from subject P3;

(iii) deletion of the fricative in the word 'the', with glottal release of the following vowel, 18 examples, all from subject P12, who also exhibited occurrence of glottal stops and glottal fricatives in other parts of the phrase (see analysis sheet in Appendix 3B);

(iv) discontinuity in phonation within vowel segments, 9 examples, from subjects P1, P5, P7, P10 and P11, (see section 4.4.2.);

(v) pre-utterance vocalisations, 3 examples, all from subject P12, (see section 4.4.2.).

Thus the data from phonologically delayed child subjects has been found, with the exceptions listed above, to be qualitatively similar in phonological form to the normal child data but quantitative analysis shows that the phonologically delayed subjects exhibit considerably higher occurrence of structural reductions and non-adult-like segment realisation compared with the normal child subjects.

4.4.4. Relationship between temporal measures and phonological form

Following the procedure employed for the adult and normal child data in the first phase of the investigation, the relationship between mean phrase duration and phonological accuracy was explored in the P Group data.

Table 40 lists the P Group subjects in order of rank (within subject group) for mean phrase duration and reports the percentage occurrence of structural reductions (deleted segments) in each subject's data and the number of non-adult-like segment realisations as a percentage of segments realised.

SUBJ.	RANK FOR MEAN PHR.DURN.	PERCENTAGE OCCURRENCE OF SEGMENT DELETIONS.	PERCENTAGE OCCURRENCE OF NON-ADULT-LIKE SEG. REALISATIONS.
P8	1	43%	22%
P7	2	42%	31%
P11	3	52%	21%
P3	4	35%	35%
P10	5	26%	19%
P4	6	28%	30%
P1	7	28%	30%
P12	8	35%	20%
P2	9	16%	19%
P9	10	17%	30%
P6	11	19%	17%
P5	12	12%	18%

Table 40. Phonological form in relation to rank for mean phrase duration - P Group subjects.

Table 40 shows a general trend for subjects with the shortest mean phrase durations to exhibit higher occurrence of structural reductions (segment deletions) than subjects with longer mean phrase durations. Relationship between mean phrase duration and occurrence of non-adult-like segment realisations is less marked but appears to be in the same direction. That is, in the P Group subjects who ranked 1 - 6 for mean phrase duration the average occurrence of segment deletions was 38%, and the average occurrence of non-adult-like segment realisations was 26%; whereas in the P Group subjects who ranked 7 - 12 for mean phrase duration the average occurrence of segment deletions was 21% and the average occurrence of non-adult-like segment realisations was 22%.

It is apparent, however, that not all the phonologically delayed children conform to these general trends; for example, subject P12 who ranked 8 for mean phrase duration exhibited high percentage occurrence of segment deletions compared with other middle ranking subjects, and P9, who ranked 10 for mean phrase duration exhibited high percentage occurrence of non-adult-like segment realisations compared with subjects of similar rank.

Thus, this investigation of the relationship, in the P Group data, between phonological accuracy and the time taken to execute the phrase has shown a trend similar to that identified in the normal child data in phase 1 of the investigation. That is, subjects who took the longest mean time to execute the phrase tended to achieve the most accurate production of the target phonological form, although relationship between mean phrase durations and occurrence of non-adult-like segment realisations was weaker in the P Group data than in the N group data.

4.5. SPEECH RATE IN THE PHONOLOGICALLY DELAYED SUBJECTS' DATA.

In the previous chapter a measure of speech rate (in segments/s) which takes account of phonological structure was devised and applied to the data from the adult and normally developing child subject groups. The rationale for using such a measure of speech rate was explained in Chapter Three, section 3.5., and centred on the expectation, confirmed by the results of the analysis of the phonological form of the adult and normal child data, that reductions of phonological structure would be found in the data and that therefore a straightforward measure of utterance duration would not provide an accurate means of comparing speech rate between subjects. When mean speech rate (in segments/s) was compared in the adult and normal child subject groups it was found that the measure resulted in a more highly significant difference between the groups than the measure of mean utterance duration (see Chapter Three, section 3.5.). The results of the perceptual analysis of the phonologically delayed subjects' data has further confirmed the need to take account of the phonological structure of utterances (number of speech sounds produced) when comparing subjects' speech rates, since there was even higher occurrence of segment deletions in the P Group data than in the N Group data.

The measure of speech rate (in segments/s) was therefore applied to the data from the phonologically delayed child subject group in order to compare speech rate in the phonologically delayed and normal child subjects. As in the first experiment, tokens which included hesitations were excluded from the speech rate measure; there were 10 such exclusions from the P Group data.

Table 41 reports the results of this speech rate measure for the P Group data. The table shows that the range of values for mean speech rate among phonologically delayed child subjects was 6.2 - 9.3 segments/s (group mean 7.8 segments/s). This compared with the range among the normally-developing child subjects of 8.5 - 12.3 segments/s (group mean 9.9 segments/s). Only 2 of the phonologically delayed subjects (P7 and P8) fell within the range of N Group values for mean speech rate.
A t-test was applied to evaluate the difference between the group mean values for mean speech rate in the two child subject groups and the difference was found to be statistically significant, ($p < .001$). (Difference between P and A Groups on mean speech rate was also evaluated using a t-test and found to be significant at the 0.1% level ($p < .001$)).

SUBJECT	**MEAN & RANGE**
P1	7.3 (6.1 -8.2)
P2	8.3 (6.9 - 9.8)
P3	7.8 (6.8 -8.9)
P4	8.4 (6.1 - 10.2)
P5	6.5 (5.8 -7)
P6	7.4 (6.2 -8.5)
P7	8.9 (7.2 -10.5)
P8	9.3 (8 - 10.5)
P9	7.9 (7.3 -9.2)
P10	8.3 (6.4 -9.9)
P11	7.1 (5.3 - 8)
P12	6.2 (4.1 - 7.4)

GROUP MEAN VALUE = 7.8 segments/s
GROUP RANGE 9.3 - 6.2 segments/s

Table 41. Speech rates (in segments/second) - P Group subjects.

The implication of this highly significant difference in mean speech rate in the two child groups is that phonologically delayed child speakers are able to achieve fewer speech segments (fewer articulatory gestures) in a given time than normal child speakers of the same age. Since such an assertion is central to the theme of this investigation, further exploration of the data was undertaken to confirm this apparent difference between the delayed and normal child subjects. This exploration involved three related analyses of selected data:

(i) Firstly, speech rate was compared in selected P and N Group tokens which consisted of the same number of segments. It will be recalled that none of the delayed subjects' tokens consisted of more than 15 perceptually distinct segments, and that this maximimum number was found in 35 of the P Group tokens. In the N Group data 39 tokens were found to consist of 15 segments.
Mean phrase duration and mean speech rate were compared in these two groups of tokens, with the following results;

Mean phrase duration in the 39 N Group tokens = 1.56 seconds.
Mean phrase duration in the 35 P Group tokens = 2.05 seconds.
Mean rate in the 39 N Group tokens = 9.8 segments / second.
Mean rate in the 35 P Group tokens = 7.5 segments / second.

That is, P Group subjects who realised 15 segments in tokens of the phrase took, on average, approximately 1/3rd longer to do so compared with N Group subjects.

(ii) Secondly, the average number of segments occurring in the shortest (fastest) tokens spoken by P and N Group subjects was compared. That is, P and N Group tokens were identified which had durations equal to or shorter than the adult subject with the shortest mean phrase duration (the shortest mean phrase duration exhibited by an adult speaker was 1100 ms, subject A7). It was found that 14 N Group tokens and 20 P Group tokens had durations equal to or shorter than this value. The mean duration of these 14 N Group tokens was 945 ms, and the mean duration of the 20 P Group tokens was 1021 ms. In spite of the direction of this difference in mean duration, it was found that the average number of segments in the 20 P Group tokens was 9.4 compared with an average of 11.4 in the 14 N Group tokens.

(iii) The third analysis involved comparing average numbers of segments realised in tokens from P and N Group subjects who exhibited similar mean speech rates. As reported above there was little overlap between the ranges of speech rate in P and N Groups, and hence this comparison was restricted to 3 subjects from each group.
Table 42 displays the results of this comparison.

SUBJECT	MEAN RATE (SEGS./S)	MEAN NUMBER OF SEGMENTS
P8	9.3	9.6
N3	9.3	15.6
P7	8.9	9.7
N2	9.1	16.0
P4	8.4	13.4
N1	8.5	14.5

Table 42. Comparison of mean number of segments realised by P & N Group subjects matched for mean rate.

It can be seen from the above table that in each case where a phonologically delayed and normal child subject exhibited similar mean speech rates, the normal subject's tokens of the target utterance were more structurally complete.

These three related analyses of selected data from the two child subject groups therefore confirm the evidence from the speech rate measure in the P and N Group data as a whole, that the phonologically delayed subjects achieved fewer speech segments, that is, performed fewer articulatory gestures per unit time, than the normal child subjects.

4.6. SUMMARY AND DISCUSSION OF RESULTS

This section begins with a summary of the results of temporal acoustic and perceptual analysis of the P Group data in relation to the results of the analysis of the adult and normal child data made in the first phase of the investigation. In the remainder of the section each aspect of the results from this second phase of the investigation is discussed in relation to the results form the first phase. In particular the discussion centres on the bearing of the results on the experimental hypotheses stated at the outset of this chapter.

4.6.1. Summary of results.

The results of temporal acoustic measurements showed that:

(i) There were no statistically significant differences between the phonologically delayed child subject group and the normal child group on measures of intra-subject temporal variability with one marginal exception.

(ii) Differences between the phonologically delayed and normal child subjects on measures of mean phrase and segment durations were not, in general, statistically significant, but there was a trend towards longer group mean durations in the P group data compared with the N group data. The measure of VOT for the initial plosive /p/ in the word 'playing' was an exception to this trend and resulted in a significantly shorter group mean value in the P group data.

(iii) Phonologically delayed subjects exhibited significantly slower speech rates than the normal child subjects on a measure of speech rate which took account of the phonological structure of their speech data. That is, child subjects in the phonologically delayed group were found to produce significantly fewer speech segments (perform fewer articulatory gestures) per unit time than the normal child subjects.

(iv) Correlations between mean duration and variability of duration for individual temporal measures were not statistically significant in the P group data, but where relationships were apparent they were negative; that is, longer mean durations were associated with low variability. This result was similar to the finding for the N group data.

(v) Investigation of the relationship between mean phrase duration and overall temporal variability across all temporal acoustic measures suggested that those phonologically delayed subjects who took the longest mean times to say the target phrase tended to exhibit lower levels of durational variability than those who took the shortest mean times to produce the utterance. This result is similar to that for the N group.

The perceptually based analysis of phonological form showed that:

(vi) There was higher occurrence of non-adult-like structural reductions and segment realisations in the P Group data than in the normal child data, and that such reductions occurred in all tokens of the experimental phrase in the P group data. However, the analysis also showed that the reduced forms found in the data from the two child subject groups were qualitatively similar; that is, there were few non-adult-like forms found in the P Group data which had not already been encountered in the N data.

(vii) Individual phonologically delayed subjects' tokens showed wide inter-subject differences in the frequency of occurrence of non-adult-like forms, and when these inter-subject differences were considered in relation to subjects' mean phrase durations a tendency was apparent for those subjects who took the longest mean time to produce the utterance to be most accurate in reproducing the target phonological form.

4.6.2. Discussion

The discussion centres first (sections 4.6.2.1. - 4.6.2.3.) on the results which have the most direct bearing on the three specific experimental hypotheses which were stated at the beginning of this chapter and are repeated here for the sake of clarity. It was hypothesised that:
i) phonologically delayed subjects would exhibit higher levels of temporal variability compared with N Group subjects;
ii) phonologically delayed subjects would exhibit longer mean phrase and segment durations than N Group subjects, especially on those segmental measures which distinguished most significantly between the

adult and normal child subjects in the first phase of the experiment; iii) phonologically delayed subjects would exhibit slower speech rates than the N Group subjects on a measure which takes account of the phonological structure of their speech data.
The remainder of the section (4.6.2.4. - 4.6.2.6.) discusses the significance and interpretation of other differences and similarities between the data from the two child subject groups.

4.6.2.1. Intra-subject temporal variability.

In the first phase of this investigation (along with most previous studies of speech motor control in adult and child speech) individual context-free temporal variability was found to be significantly greater in young children's speech than in adult speech. In the second phase of the investigation levels of intra-subject temporal variability have been found to be similar in phonologically delayed and normally developing child subject groups, with the exception of the variability of VOT of /t/ in the word 'two' for which a difference significant at the 5% level was found. That is, the hypothesis that this key indicant of maturity of speech motor control would distinguish between phonologically delayed and normally developing children is refuted.

The lack of significant difference in temporal variability between the two child subject groups found in this investigation is consistent with the findings of Catts & Jensen's (1983) study, which has been discussed above. In that investigation no significant difference in intra-subject relative variance was found between a group of 9 phonologically disordered and 9 normal children on measures of vowel duration and consonant closure duration in multiple token samples. This finding tends to contradict the other results from their study, but the authors do not suggest any satisfactory explanation for this anomalous finding except that " factors other than articulatory precision may affect the variability of segment durations" , and, in particular, that "differences in variability of a global timing factor .....may have masked differences in the variability of segmental timing", (p507). However, the results obtained in the current investigation do not give credance to such a suggestion, since group means were not found to be significantly different in the two child groups for either individual coefficient of variation for speech rate or for individual coefficient of variation for phrase duration.

4.6.2.2. Absolute phrase and segment durations.

Group mean differences for phrase and segment durations between the two child groups were in the direction of longer durations in the P group data, with the exceptions of the VOT of the initial plosive in the word 'playing' for which a significantly shorter group mean duration was found in the P Group compared with the N Group, and the VOTs of the initial plosives in the words 'two' and 'boys' for which there was negligible difference between the group means in the two child groups.

On those measures in which longer mean durations occurred in the P Group data, the differences between group means in the two child groups did not reach statistical significance. However the most marked differences between the P and N groups were found for the two measures of consonant closure duration, which, it will be recalled, also showed the greatest differences between the normal child and adult data of any of the mean durational measures. The general trend therefore is for those measures which distinguished most significantly between the adult and normal child subjects to show even greater differences between adults and phonologically delayed child subjects; that is, the general trend in the results of the mean durational measures tends to support the second experimental hypothesis, although such a conclusion can only be tentative since results are not statistically significant.

It is of interest that Catts & Jensen's investigation also found longer consonant closure durations in their phonologically disordered subjects than in their normal subjects, and in that investigation the difference between the group means was statistically significant ($p < .05$). It will be recalled that in the previous chapter (section 3.6.2.2.) it was suggested that the significantly longer consonant closure durations found in the N group data compared with the A group data could be explained by a relative lack of ability, in the child subjects, to execute co-ordinated actions of the oral and laryngeal mechanisms at speed. If such an explanation is acccepted for the difference between normal children and adults then the explanation for the differences in mean consonant closure durations found in normal and phonologically delayed/disordered child subjects in this and in Catts & Jensen's experiment may also lie in differences of maturity of neuromotor co-ordination abilities. There is further discussion of this aspect of the results in the final chapter.

In the current investigation the measure of mean vowel duration, in the word 'boys', resulted in a longer group mean value in the P Group than in the N Group, but the difference between group means was small and did not reach statistical significance. In Catts & Jensen's experiment a similar result was obtained in relation to vowel duration measures, that is, longer, but not statistically significantly longer, mean vowel durations were found in data from phonologically disordered subjects compared with normals. It should be noted that in the current experiment group mean vowel duration was shorter in **both** child groups than in the adult group, which would imply that whatever factors influence the N Group subjects towards the production of relatively short vowels in this context also apply to the phonologically delayed child subjects, (see Chapter Three, section 3.6.2.2.).

The result of the measure of VOT in the initial plosive in the word 'playing' in the P group data contradicts the second experimental hypothesis that longer mean segment durations would be found in the P Group data than in the N Group data. However, it can be argued that the general hypothesis proposed in this investigation, that phonologically delayed children have less mature speech neuromotor abilities than normally developing children of the same age, does **not** in fact lead to an expectation of longer mean durations in the P Group subjects in this particular instance, since it is widely accepted that the production of plosive consonants with short voicing lag times is motorically (physiologically) less demanding than the production of plosives with long voicing lag times. The following statement from Hawkins (1984) emphasises this point;

> "The late establishment of mature VOT for long-lag stops has been commonly accepted as resulting from differences in the neuromotor co-ordination required: short-lag stops are thought to allow considerable variability in the co-ordination of laryngeal and oral activity, whereas long-lag stops demand rather precise co-ordination." (p 325).

In the early stages of speech development all plosives tend to be produced with short voicing lag times, followed by a gradual, and initially covert, progression towards achieving an adult-like distinction between short and long VOTs in the contexts of voiced and voiceless plosive targets, (Macken & Barton 1979). This developmental progression is regarded as involving both the acquisition of knowledge of the phonemic distinction between voiced and voiceless plosives and the gradual acquisition of the neuromotor co-ordination skills required in the production and control of long-lag VOTs. Thus in this particular context (VOT in a voiceless plosive target), **shorter** rather than longer duration might be expected in subjects with the least mature speech neuromuscular co-ordination and control.

Comparison between P and N Group subjects on the measure of VOT in the initial voiceless plosive in the word 'two' yielded rather different results however. That is, group mean values in the two child groups for **this** measure were quite similar, (the P Group mean = 74 ms; N group mean = 70 ms). In fact, there was a tendency for P Group subjects to produce both more tokens with extremely short VOT and more tokens with extremely long VOT in this context than the N group subjects (see figure 38), which suggests that the P Group includes children at various stages in the acquisition of the voicing contrast. That is, some P Group subjects are at Macken & Barton's stage IIIa at which fairly consistent distinction between the ranges of VOTs in the contexts of voiced and voiceless targets is achieved, but at which control over the exact duration of voicing lag is not yet adult-like, and voiceless targets are sometimes produced with extremely long VOT. (See also Tyler & Saxman, 1992.)
On the other hand, some P Group subjects, for example subjects P4 and P9 are at an earlier stage of development of the voicing contrast (Macken & Barton's stage I) and tend to produce all plosives with VOTs in the short-lag range.
These findings are similar to those in Catts & Jensen's investigation where it was found that some phonologically disordered subjects tended to produce short voicing lag times in the context of both voiced and voiceless plosive targets. These subjects were labelled 'non-contrastive' by Catts & Jensen and were regarded as being at Macken & Barton's stage I. Other disordered subjects in the same experiment were found to produce long voicing lag times which were

appropriate to the target context but which were significantly **longer** than those produced by N subjects. See also Tyler & Saxman, 1992.

The results of both temporal acoustic and perceptual analysis of the data in the current investigation show quite marked dissimilarity with respect to the VOTs exhibited by phonologically delayed subjects in the contexts of these two voiceless plosive targets (/t/ in 'two and /p/ in 'playing'). That is, P Group subjects produced more voiced realisations of the voiceless plosive target in 'playing' than of the voiceless plosive target in 'two', (87 compared with 49); [check these figures] although P Group subjects produced more voiced realisations of **both** these target segments than the N Group subjects. A possible explanation is that (most) phonologically delayed subjects, as well as the normal child subjects, have adequate knowledge of the features which distinguish voiced and voiceless plosives, but P Group subjects do not have sufficiently mature neuromotor control over the production of the motorically more demanding long-lag VOTs to enable them to achieve appropriate realisation in all contexts. That is, the phonologically delayed subjects may have poorer (less mature) skill in controlling the production of long voicing-lag stops and find the particular context of the voiceless plosive target in the word 'playing' which occurs embedded within the utterance and in a relatively unstressed context **more** demanding than the initial voiceless target in the word 'two' which occurs initially in the utterance and in a strongly stressed context. It is also possible that the consonant cluster context in which /p/ occurs in the target utterance may have a bearing on the findings. That is, some P Group subjects, although unable to produce a consonant cluster in this context, may be aware of the second voiced element of the target cluster, which may have influenced the voicing characteristics of the plosives produced.

As has been pointed out, some P Group subjects (P4 & P9), do not yet have the ability to achieve long voicing lag times in either of these contexts: Subject P3, who realises the initial segment of 'playing' as a voiced plosive [b] in all tokens and replaces the initial plosive in 'two' by a glottal stop in all tokens, presumably also is at a stage of development in which the production of plosives with long voicing lag times are beyond his neuromotor capacity, but this child has adopted different strategies for dealing with this difficulty in these two different contexts.

Such an interpretation of the findings is consistent with the view that there is a gradual developmental progression towards fully adult-like control over the production of short and long VOTs which depends on the gradual maturation of neuromotor skill. It is also consistent with the view that while the speech motor control of both normally developing and phonologically delayed children in this age range is still developing, children classified as phonologically delayed are at an eariler stage of speech motor control development compared with other children of the same age.

4.6.2.3. Speech Rate

The hypothesis that speech rate (measured as mean number of segments produced per second over a subject's tokens of the phrase) would be slower in the P Group data than in the N Group data was upheld by the results which showed a highly significant difference between the two child subject groups. Since rate of execution of a motor activity is a key indicant of level of motor skill, this finding that phonologically delayed child subjects achieved significantly fewer speech segments (articulatory movements) per second than normal child subjects supports the main hypothesis that phonologically delayed children have less mature speech motor abilities than children of the same age who are acquiring the phonological system of the language normally.

4.6.2.4. Relationships between mean durations and temporal variability.

Relationships between absolute durational measures and temporal variability measures in the P Group data were found to be broadly similar to those found in the N group data in phase 1. That is, there was a general trend in both groups for shorter mean durations to be associated with higher levels of temporal variability, although the trend was less pronounced in the P Group data than in the N data. As was discussed in the previous chapter a possible interpretation of these findings is that when young child speakers, who have limited speech neuromotor capacity compared with adults, attempt to execute an utterance within a time frame similar to, or even shorter than, those exhibited by most adult speakers, the extra demand placed on their speech motor capacities results in inability to maintain precise control over segmental timing.

4.6.2.5. The Phonological form of the data.

The finding that phonological form in the P Group data was, to a large extent, qualitatively similar to the N group data was striking and unexpected. It was argued above (Chapter Three, section 3.6.2.4.) that reduction of phonological form in the speech of normally developing children serves to lessen the demand placed on the child's immature speech neuromotor capacity, just as mature adult speakers employ reduced connected speech forms to maximise efficiency of articulatory effort. The finding of qualitative similarity but quantitative dissimilarity between the two child groups suggests that all children in this age group, who are in the process of acquiring adult speech patterns, need to economise on articulatory demand (at least some of the time) by reducing the phonological form of utterances with respect to adult target forms, but that children who are classified as phonologically delayed need to make more extensive use of such a strategy than normally developing children. It is logical to argue that this need arises from phonologically delayed children's more limited speech motor capacities.

The fact that in both child groups, reduced forms which occurred variably and reduced forms which occurred consistently in individual subjects' data were found, but that consistently occurring reduced forms were more common in the P Group data, indicates that such reductions (simplifications) are more likely to be 'obligatory' for the P Group subjects. This suggests 'absolute' limitations on their speech production. It could be argued that this finding is consistent with the view that the P Group subjects have less mature speech neuromotor skills than the N subjects; that is, that more of the segments of the phrase are beyond the neuromotor capacities of phonologically delayed children and must be realised by them in reduced form in all tokens of the phrase. Conversely, it could be argued that consistently occurring non-adult-like forms are evidence of deviant or delayed phonological organisation and that neuromotor ability has no bearing on their occurrence. The relative merits of these possibilities and their possible inter-relatedness has an important bearing on the question of the interaction between neuromotor maturation and phonological acquisition and this issue is discussed in the final chapter.

The similarity between the non-adult-like forms found in the data from the two child groups has been emphasised: however, as reported above, there were **some** non-adult-like forms which were unique to the P Group data, (see section 4.4.3. above). These were; glottal replacement of the initial segment of the phrase, other non-adult-like occurrence of glottal stops and glottal fricatives, fronted realisations of the fricative in the word 'boys', pre-utterance vocalisations, and discontinuities of phonation within vowel segments. In the final chapter these non-adult-like forms which were unique to the phonologically delayed child subject group are discussed in relation to the main hypothesis; that is, it is argued that each of these forms, which occurred in P Group data but not in the N data, is consistent with less mature speech neuromotor abilities in the phonologically delayed children and can be explained on the basis of limitations of speech motor capacity.

4.6.2.6. Relationship between temporal measures and phonological form.

The interpretation of the relationship between mean phrase duration and occurrence of structural simplifications has been discussed above (Chapter Three, section 3.6.2.5.), and the same questions and comments apply to the P Group data.
There was some evidence of a tendency in the P Group data for longer mean phrase duration to be associated with lower occurrence of non-adult-like segment realisations, although this trend was less marked than in the N data. A possible reason for the difference between the two child groups in this respect is that, as stated in 4.6.2.5. above, there are more instances of 'obligatory' occurrence of non-adult-like forms in the P data than in the N data.If these forms represent absolute limitations on a child's speech output then their occurrence will not be related to the speed of execution of the phrase. That is, only segments which a child is capable of producing in adult form in 'optimum circumstances' will show a relationship between occurrence of non-adult-like realisations and speed of execution of the phrase. Since a greater proportion of the non-adult-like forms in the P data than in the N data fall into the category of 'absolute limitations' this might explain the relatively

weak relationship between mean phrase duration and the occurrence of non-adult-like realisations in the P Group data compared with the N Group data.

4.6.3. Summary

This second phase of the investigation has shown that two of the three experimental hypotheses were upheld by the data; that is, significantly slower speech rates, assessed as the number of perceptually distinct speech segments produced in unit time, were found in the P Group data compared with the N Group data; and longer, although not significantly longer, segment durations, for those segments which had distinguished most significantly between adults and the normal child subjects in phase 1, were found in the P Group data. This combination of findings supports the main hypothesis that neuromotor control for speech is less mature in phonologically delayed children than in normally developing children of the same age.

However, the other experimental hypothesis was refuted by the data; that is, with one marginal exception there were no significant differences between the two child groups on measures of temporal variability. This finding argues against the main hypothesis. A possible explanation for these discrepant findings is explored in the final chapter where the findings in relation to the specific experimental hypotheses together with other aspects of the results from both phases of the investigation are discussed with respect to the main hypothesis and with reference to the question of the relationship between development of speech neuromotor abilities, phonological acquisition and phonological disability.

CHAPTER FIVE

DISCUSSION & CONCLUSIONS

This final chapter begins with a brief resume of the results of the two phases of the investigation (section 5.1.), followed by discussion of the results in relation to the main hypothesis that phonologically delayed pre-school children have less mature speech motor control than their normally developing peers and that this immaturity is implicated in their phonological acquisition difficulties. That is, conclusions are drawn as to the extent to which this hypothesis is supported by the results (section 5.2.).

Next, in section 5.3.1., the results are explored with respect to the question, posed in Chapter One, of the relationship between the development of speech motor abilities, the development of the neurophysiological systems underlying speech production, and phonological acquisition.

Section 5.3.2. discusses the results of the investigation in relation to current therapy procedures for phonological disability and the following section (5.3.3.) makes some speculative suggestions concerning the possible bearing of the results on the issue of intrinsic versus extrinsic theories of speech timing control.

Section 5.4. gives a critical evaluation of the methodology of the investigation and possible future research arising from the investigation is discussed in section 5.5.. The final section summarises the thesis, draws together the discussion of results and states the conclusions drawn from the investigation.

5.1. SUMMARY OF MAIN RESULTS.

The investigation has confirmed the findings from previous studies, reviewed in Chapter Two, that young children and adults exhibit significant differences on measures of maturity of speech motor control. That is, both groups of child subjects exhibited higher levels of temporal variability than adult subjects; longer mean phrase durations and (with one exception) longer mean segment durations than the adult subjects, see sections 3.3.3.1, 3.3.3.2.

and 4.3.3.4.). Group mean speech rate (measured in segments/second) was significantly slower in both child groups compared with the adult group (see sections 3.5 and 4.5), and the significance level of this difference was even greater than for differences of mean phrase duration, reflecting the tendency for child subjects to reduce the phonological structure of the target phrase. Adult and child subjects also differed in terms of the relationships between mean phrase duration (mean time taken to execute the experimental phrase), temporal variability and accuracy of reproduction of the phonological form of the target phrase. That is, in the adult data no relationships were apparent between mean phrase duration and these other aspects, whereas, in the child data a tendency was apparent for fast execution of the phrase to be associated with high levels of temporal variability and inaccurate and inconsistent reproduction of the target phrase.

Support for the main hypothesis, that phonologically delayed pre-school children have poorer speech motor control than their non-delayed peers, rested on showing significant differences between the two child subject groups on these same measures, and in particular on those measures which had distinguished most significantly between adult and normal child subjects. Of the three specific experimental hypotheses tested in the second phase of the investigation the first, that phonologically delayed child subjects would exhibit higher levels of temporal variability than normal child subjects was refuted by the results; the second, that P Group subjects would exhibit longer phrase and segment durations than N subjects was partly supported by the results, although differences between the groups were not statistically significant; and the third, that speech rates in the P Group would be slower than in the N Group, was strongly supported by the findings.

5.2. THE RESULTS IN RELATION TO THE MAIN HYPOTHESIS

These three main aspects of the results are now discussed in relation to the main hypothesis, together with discussion of other aspects of the results which bear upon the relative status of speech motor control in the two child groups.

5.2.1. Results which tend to support the hypothesis.

Those aspects of the results which support the hypothesis that speech motor control is less mature in the P Group subjects compared with the N Group subjects are considered first.

5.2.1.1. Speech rate measures.

The result which most strongly supports this hypothesis is the finding of significantly slower speech rates (measured as segments produced per unit time) in the P Group compared with the N Group of child subjects. That is, this measure demonstrates a phonetic difference (rate of articulation) between these two groups of children who are distinguished by their level of phonological development.

Since rate of execution of a motor activity is assumed to be a key indicant of level of maturity of motor skill, the finding that phonologically delayed subjects achieved significantly fewer speech segments (articulatory gestures) per second argues strongly that these subjects as a group have less mature speech motor abilities than the N Group of subjects.

It would be of interest to determine whether a measure of speech rate in terms of number of **syllables** produced per unit time would **also** distinguish significantly between the normal and phonologically delayed child subjects. Such information would inform discussion of the level at which motor co-ordination and control is limited in phonologically delayed children in comparison to normally developing children. That is, it may be that phonologically delayed children in fact produce the same number of **syllables** per unit time as normal children but these syllables are of less complex type than in other children's speech, resulting in phonologically delayed children exhibiting slower segmental speech rates. Such a finding might imply that phonologically delayed children have adequate control over the co-ordinative structures responsible for cyclical vowel to vowel production, but that there are constraints on the operation of those co-ordinative structures which control consonant production within the time frame set by that cyclical vowel production, (MacNeilage & Davis 1990).
On the other hand it may be that phonologically delayed children are

as different from normal children on a syllable rate measure as they are on a segmental rate measure, which might imply constraints on the operation of the co-ordinative structures which underlie both vowel to vowel movements and the consonantal modifications which are superimposed on them.

I have, in fact, made an attempt to try out such a syllable rate measure on the data, but the results have been inconclusive: when speech rate in syllables/second was calculated for the six N Group subjects and the six P Group subjects who exhibited the slowest rates within their subject groups on the segments/second measure, the difference between them was small; that is, a mean of 4.1 syllables/s for the six N subjects compared with a mean of 3.9 syllables/s for the six P Group subjects.
It was concluded that it was not worth extending this measure to the whole data since, because the experimental phrase consisted of a maximum of only 8 syllables spoken over a time span in the order of 1 - 2 seconds, a measure of speech rate in syllables/s is bound to result in a very narrow spread of values, making comparisons between subjects of limited value. It would be interesting to compare phonologically delayed and normally developing children on a measure of mean syllable rate over a longer utterence (such an investigation is proposed in section 5.5.2. below).

5.2.1.2. Segment durations.

The hypothesis is also given (more tentative) support by the results of the two measures of consonant closure duration. In Chapter Three (3.6.2.2.) an argument was made for regarding the longer closure durations in the N data compared with the A data as resulting from the child speakers' relative inability to achieve rapid and precise integration of the required laryngeal and oral actions. By extension, the even longer closure durations found in the P Group, although not statistically significant, might be indicative of even less mature ability to perform the required co-ordinated gestures.

The results of the VOT measures for the two voiceless plosive targets in the experimental phrase (/t/ in the word 'two' and /p/ in the word 'playing') also tend to support the main hypothesis. These results were discussed in some detail in section 4.6.2.2., where it was shown that the differences between the P and N Groups' results on these measures are compatible with the view that the phonologically delayed child subjects (as a group) were at an earlier stage of speech motor development than the N subjects. The argument will not be reiterated here and the reader is referred to the relevant section.

5.2.1.3. The phonological form of the data.

In section 4.6.2.5., it was argued that the finding that the data from both groups of child subjects exhibited qualitatively similar non-adult-like forms but that occurrence of these forms was more widespread in the P Group data than in the N data is compatible with the view that speech motor production abilites, which are limited as compared with adult speakers in **both** child groups, are **more** limited in the P Group subjects. That is, when these two groups of child subjects reproduced a target phrase **within similar overall time frames** the phonologically delayed subjects appeared to need to reduce the articulatory demands of that target phrase **more** than the N subjects, presumably because the P Group subjects were limited by their less mature speech motor capacties. Their need to reduce articulatory demand (that is, to reduce the number and extent of articulatory gestures performed) was manifested as more widespread reduction of the phonological structure of the target utterance; greater tendency to 'opt' for motorically less demanding segments and sequences of segments and greater occurrence of imprecisely articulated segments than in the N group data.

Although the most striking outcome of the perceptual analysis of the data from the two child groups was the degree of similarity between the non-adult-like realisations encountered, **some** characteristics which were unique to the P Group were also pointed out (see sections 4.4.3. and 4.6.2.5.). It was stated in Chapter Four that these forms, found only in the P Group data, are consistent with less mature speech neuromotor abilities in the P Group compared with the N Group. These characteristics unique to P Group data were: glottal replacement of the initial segment of the phrase; other non-adult-like occurrences of glottal stops and glottal fricatives; fronted realisations of the fricative in the word 'boys'; pre-utterance vocalisations and discontinuities of phonation within vowel segments. Each is now briefly discussed in relation to the extent to which it supports the hypothesis.

It seems possible to view glottal replacement of consonant segments as a strategy to avoid attempting production of segments which are beyond a child's neuromotor capacity: certainly others have favoured such an explanation; for example, Grunwell (1982) describes a phonologically disordered child of 6 years who exhibited extensive use of glottal replacement, and suggests that "he appeared to use this pattern to avoid less practised, more complex articulatory sequences". (p189).

The occurrence of fronted realisations of the fricative in the word 'boys' in the P Group data is also consistent with greater limitations on neuromotor capacity compared with normal subjects. That is, in the great majority of N Group tokens this segment is realised as a fricative with (approximately) alveolar placement, with only occasional examples in any one child's data of stopped realisations of the segment or deletion of the segment: phonologically delayed subjects, however, are much less likely to achieve the target features of this segment (there are many examples of deletions and stopped realisations). In particular, the data from subjects P2 and P3 suggests that these children are at a stage at which they can achieve an approriate **manner** of articulation for this segment but are not yet able, on all occasions, to make the articulatory adjustments necessary to produce a fricative with **alveolar** placement in this context (in which the preceeding and succeeding consonant segments are bilabial stops), and sometimes employ a place of articulation which requires less extensive articulatory manoeuvre.

The occurrence of vowel segments in which discontinuities of phonation were noticed in the P Group data is also consistent with more limited neuromotor co-ordination abilities in these subjects, (see section 4.4.2.). In the investigations by Amorosa et al (1986 & 1990), see section 1.3.2.4., 'intraphonemic disruptions' in phonation, and other abnormalities of voicing, were found in data from speech disordered subjects but not in data from control group subjects and the authors argue that such findings are indicative of deficits of fine motor co-ordination. They suggest that in their 'unintelligible' children this deficit affects articulatory,

phonatory and speech breathing

systems. It is also of interest in this context that one P Group subject (P12) in the current investigation exhibited pre-utterance vocalisations in some of his tokens (see section 4.4.2.), since Amorosa et.al. report high incidence of pre-utterance vocalisations in their speech disordered group and regard this as further indication of a motor co-ordination deficit.

Interpretation of the finding that in the P Group data non-adult-like forms were more likely to be 'obligatory', that is,occur in all tokens from an individual subject, than in the N group data is now discussed in relation to the main hypothesis.

It can be argued that non-adult-like forms which occur in **all** of a subject's tokens represent absolute limitations on the child's speech production capacities; that is, the child has not, as yet, succeeded in implementing a combination of articulatory manoeuvres which results in an output form which matches the adult target form of a particular word or segment (at least not in the context of this particular phrase). On the other hand, a child who produces adult-like realisations of a particular word in **some** tokens and non-adult-like realisations in others must be in the process of incorporating a satisfactory 'scheme' for the production of that target word into his speech output; but, execution of that scheme is not yet fully reliable and is liable to be disrupted by other demands of the utterance (including the speed at which the utterance is executed).

Such an explanation for this difference between the P and N data is consistent with the main hypothesis that speech motor production capacities are less well developed in the P Group subjects than in the N Group subjects; that is, phonologically delayed subjects have 'discovered' and are in the process of automatizing a more limited range of successful motor schemata for the reproduction of adult target forms than N subjects. However, a view of phonological disorder as a purely linguistic/cognitive dysfunction would presumably regard non-adult-like forms which occur in all of a subject's tokens as evidence of deviant phonological organisation at a central level. In section 5.3.1. below this discussion is developed in relation to the inter-relatedness of speech motor development and learning and phonological development.

5.2.2. Results which jeopardise the main hypothesis.

The results of the measures of temporal variability in phase two of the investigation refuted the specific experimental hypothesis that higher levels of temporal variability would be found in the phonologically delayed child subjects than in the normal child subjects. As stated at the outset of the investigation, consistency of performance is one of the key indicants of level of maturity of a motor skill, and in the first phase of the investigation all measures of temporal variability distinguished significantly between adult and normally developing child speakers. The failure to find, with one exception, any significant difference between the P and N subject groups on these same measures argues against the main hypothesis and the discrepancy between this finding and the other findings already discussed in this section means that it is not possible to draw any firm conclusions in relation to the main hypothesis on the basis of the results of the investigation as a whole.

A possible explanation is now explored which might allow the finding of no difference in temporal variability between the two child subject groups to be reconciled with acceptance of the main hypothesis; that is, it is suggested that as speech neuromotor abilities mature, the consequent increase in speech production capacity does not have equal or simultaneous impact on all aspects of speech production (and therefore on all measures in this investigation). That is, as children's speech neuromotor skills mature the 'extra' capacity might be used first in achieving those characteristics of adult speech forms which are most perceptually salient to the child; that is, those which have contrastive, meaning-carrying function and therefore have most impact on the 'success'/effectiveness of the child's communicative attempts. Such supposed 'first-line' targets would include signalling adult phonological contrasts, including those timing features (such as VOT contrasts) which have a meaning carrying function.

Only at a later stage, perhaps after the age of about four years when normally developing children have, by and large, succeeded in signalling most of the range of phonological contrasts of the language, will **further** increase in speech neuromotor capacity begin to be available for matching adult levels of precision over less perceptually salient aspects of speech production such as precise and consistent control of segment durations (observable in multiple token speech samples) and matching adult durational values of features which do not have meaning carrying function (such as consonant closure durations).

If, as suggested by such an argument, temporal precision for non-meaning carrying temporal features begins to move towards adult levels only after children have achieved adequate control over more 'essential' or perceptually salient aspects of production, then the lack of difference between the P and N subject groups on measures of temporal variability can be explained, since all these children are still at a stage of development at which their limited neuromotor capacities are concentrated on the most communicatively salient aspects of speech production. Of course, this possible explanation can be no more than conjecture on the basis of the evidence available from this investigation; although some support is given by Smith (1992) who suggests that temporal variability is developmentally much slower to approximate to adult values than are absolute durational values. A further investigation which could be constructed to evaluate the above suggestion is outlined in section 5.5.1. below.

5.2.3 Summary

The investigation has yielded mixed results. That is, as shown above, several aspects of the results tend to support the hypothesis, while one aspect tends to refute it and therefore prevents a firm conclusion in favour of the hypothesis. This combination of findings had not been forseen; that is, it had been anticipated that the specific experimental hypotheses tested in the second phase of the investigation would stand or fall together. A possible explanation for the anomalous result relating to temporal variability has been discussed, but evaluation of this suggested explanation requires a further investigation and therefore cannot be pursued further at this stage. It is, of course, possible that the mixed results obtained in this investigation might be replicated in future research, which would pose questions as to which kinds of measure should be regarded as valid indices of speech motor control ability. In fact, the assumption that absolute durational measures and temporal variability measures are equally useful, and interchangable, indices of speech neuromotor maturation, has recently been questioned (Smith, 1992). However, since further discussion of temporal variability in phonologically delayed and normal children must await further investigation, the discussion in the following section centres on the remaining findings; that is, on those results which indicate that speech motor skills are less mature in the P Group than in the N group subjects.

5.3. FURTHER DISCUSSION OF RESULTS

This section discusses, in the light of these results, the main issue raised at the outset of the thesis; that is, the issue of the relationship between children's phonological development and development of speech motor co-ordination and control. The areas for discussion include exploration of the ways in which the phonetic differences (indicative of differences of maturity of speech motor skills) found between adult speakers, normally developing child speakers and phonologically delayed child speakers might relate to and underlie the apparent differences in phonological performance: consideration of the possible neurophysiological basis for the maturation of speech motor skills is integral to this discussion. In section 5.3.2. implications for the rationale and design of therapy procedures for phonological disability, which is of particular interest to the author, are considered, and section 5.3.3. attempts to relate the findings of the investigation to theoretical issues in the control of speech timing.

5.3.1. Relationship between development of phonetic (motor speech production) skills and phonological acquisition.

The first phase of the investigation has demonstrated phonetic (motor speech production) differences between the speech data from adult speakers and data from young normally-developing child speakers and in the second phase of the investigation phonetic level differences have been demonstrated between two groups of children who are distinguished, on the basis of analysis of speech samples and diagnosis by speech therapists, by their level of phonological development. These differences have been described and discussed.

The question is now addressed of how the apparent differences in speech motor capacity among adult speakers, normally developing children and phonologically delayed children, suggested by this investigation, might underlie differences in their phonological performance. Discussion will focus first on children whose speech acquisition is proceeding normally, followed by discussion of the ways in which slower maturation of speech motor skills might have a limiting effect on the progress of phonological acquisition in some children (those labelled as phonologically delayed or disordered).

5.3.1.1. A model of speech production which provides a basis for the following discussion.

A model of speech production proposed by Hewlett (1990) which was described briefly in section 1.5.1. offers a powerful tool for exploring the way in which a child's gradual acquisition of the phonological system of the language might occur in relation to, and interdependence with, the gradual maturation of his speech motor capacities. Hewlett's model is included again here, in figure 51, for clarity and ease of reference.

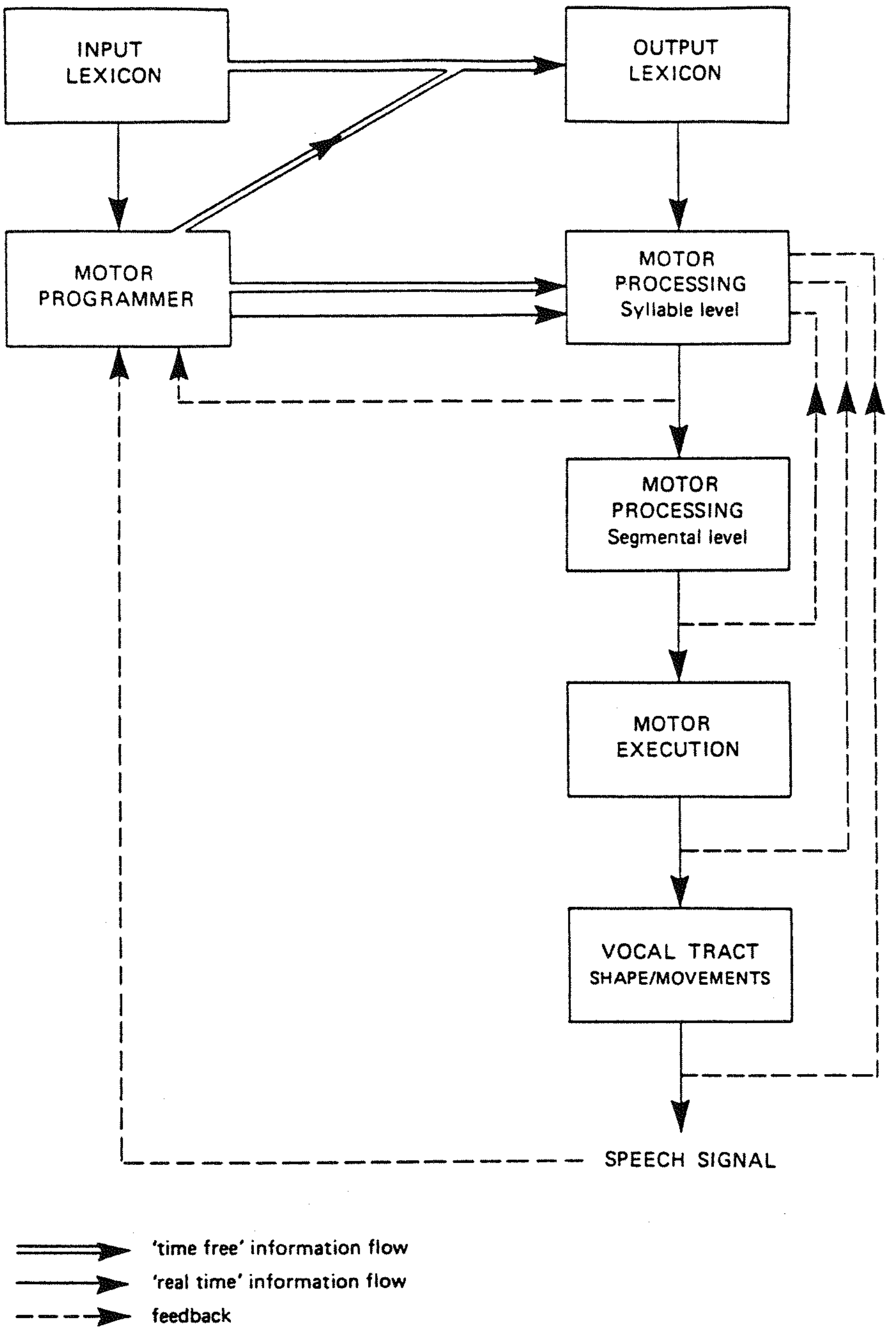

Figure 51. A model of speech production (Hewlett, 1990)

This model is based on the premise that the words which a child recognises are stored in the 'Input Lexicon' in terms of auditory-perceptual features which match the features of the adult forms which the child hears, at least within the limits of the child's current perceptual abilities. A Motor Programming component receives its input direct from the Input Lexicon and then has the task of devising a motor plan for the production of these auditory-perceptual targets. This motor plan is then passed to a Motor Processing component which must "assemble the sequence of gestures involved in pronouncing the word, and determine the precise values of the articulatory parameters involved" (Hewlett 1990, p31). This is a slow, laborious and unautomatized route for the production of an utterance.

Hewlett's model also provides for an alternative, faster, automatized means of executing a desired target:

> If or when a plan proves (reasonably) successful it can be used as a basis for devising the relevant mapping rules, in terms of feature values, from the Input Lexicon to the Output Lexicon. At the same time, as the system becomes more practised at implementing the plan, its implementation can be increasingly delegated to the Motor Processing component. In this way, motor implementation becomes more automatized. (Hewlett 1990 p29)

Progression from use of the slow, unautomatized route to rapid, automatized production of an utterance depends upon the Motor Programmer receiving feedback from all 'down-line' stages of the speech production process and, on the basis of the feedback 'evaluating' the success of a motor plan. That is, the Motor Programmer assesses whether the Motor Processing component has assembled the plan according to the instructions it received; whether the assembled plan was successfully translated into muscular contractions and articulator movements and finally whether the resulting speech signal was an acceptably close match with the perceptual/acoustic target drawn from the Input Lexicon. On the basis of this evaluation the Motor Programmer either tries another plan or allows the existing plan to be used to devise mapping rules for the Output Lexicon which on subsequent occasions will provide input directly to the Motor Processing component for 'automatic' execution of the item.

The present writer believes that the nature and motivation of the 'criteria' employed by the Motor Programmer for accepting a motor plan and allowing its subsequent automatization are of paramount importance in relation to phonological development and this argument is developed below.

5.3.1.2. Motor implementation of speech at the outset of speech development.

It is self evident that young children have less ability to control the performance of finely co-ordinated motor activities than older children and adults; witness, for example, children's gradual progress between the ages of say 2 to 5 years on tasks such as fastening buttons, threading beads, building towers with blocks etc., (see Sheridan 1975). Such skills are known to undergo a gradual development in the early years of life which depends on a combination of neuromuscular maturation and learning. As discussed in Chapter One there is a large body of evidence to suggest that speech motor control also develops gradually throughout childhood. It has been seen that the youngest children involved in studies from which this evidence is drawn have been around 3-4 years of age. It must be assumed children in younger age groups have not been involved because of the practical difficulties of obtaining speech samples, particularly multiple token speech samples, from children below 3 years of age. However, it can safely be assumed, on the basis of the existing evidence that, at the age when speech development begins, speech motor control is even less well developed than in the youngest children studied in these investigations. That is, all children must embark upon the task of learning to use speech as a means of communication (that is, learning to produce the meaning-carrying sound combinations and contrasts of language) at a time when their motor resources are severely limited in comparison with the adult speakers whom they attempt to emulate.

In the very earliest stages of speech acquisition, often referred to as the 'first fifty word stage' (Ingram 1976) the child's attempts to reproduce adult forms are organised at a 'whole word' level with little attempt to reproduce the individual phones of the target utterance. That is, at first the Motor Programmer attempts only to devise a 'holistic' plan and only gradually takes on the role of attempting to devise plans to reproduce the full phonological form of words. Children's utterances are characteristically variable in phonological form in the early stages; but other aspects, including vowel quality and length; number of syllables and stress pattern, are sufficiently consistent from one occasion to the next to enable a listener to judge that a child is associating a particular vocalisation with a particular object or event in the environment (that is, that the vocalisation has meaning). Although there is evidence that children's perceptual abilities develop ahead of their speech production abilites, it cannot be assumed that in the early stages of speech development the child stores full segmental, phonological forms of words in an input lexicon. It may be that the target forms (input lexicon forms) which the child attempts to reproduce are, themselves, variable and only crudely represented at this early stage in speech acquisition. At a slightly later stage of speech development, as the child's speech motor skills and, perhaps, also perceptual abilities become more refined, the Motor Programmer begins to 'take on' the additional task of devising motor plans which will result in output forms which match the phonological characteristics of the target forms.

At these earliest stages of speech development when the majority of a child's communicative attempts are single-word utterances, the child employs the slow, unautomatized route to the motor implementation of a word, in which, each time a particular word is required, the Input Lexicon form is accessed and the Motor Programmer attempts to devise a plan for its reproduction. The Motor Programmer is likely to try different possible plans for a single word on successive occasions, resulting in the characteristic variability of phonological form in the speech of children at the earliest stages of speech development.

5.3.1.3. Beyond the single word utterance stage of development.

As the child's linguistic competence increases and the length and complexity of his attempted utterances increases, his speech production mechanism is under increasing pressure to implement speech rapidly and automatically. That is, except at the very earliest stages of spoken language use it is not a viable option for a child to use the slow route from perceptual target to Motor Programmer to Motor Processing every time he wishes to utter a word or phrase. That is, in order to move on from the very earliest stages of speech acquisition a child must be able to assemble an utterance at speed from a set of motor schemata which are stored in readiness somewhere in the system: he cannot, everytime he needs a particular lexical item or combination of speech segments, set about devising a new motor plan to match an adult-like perceptual target.

The need to be able to execute speech rapidly and automatically dictates that the Motor Programmer must allow a motor plan for an utterance to be passed over as soon as possible to the 'fast' route via the Output Lexicon and Motor Processing component. That is, the pressure to achieve a high degree of automaticity in the implementation of speech is of great significance in determining the criteria by which the Motor Programmer 'decides' on the acceptability of a motor plan, and therefore in determining what output forms become automatized and 'phonologised' in the child's output.

What might be the criteria by which one particular motor plan, from several which the Motor Programmer has devised for a particular utterance, becomes entered into the Output Lexicon and provides the input to the Motor Processing component on subsequent occasions? The most obvious criterion is closeness of match between the resulting acoustic speech signal and the adult form of the utterance which is stored in the child's Input Lexicon. However, since, as indicated by the results of this and previous investigations, children in the process of speech acquisition are significantly limited in their speech motor control abilities in comparison with adult speakers, it may be that **none** of the motor plans devised by the Motor Programmer for a particular utterance will be executed by the speech production mechanism with sufficient accuracy and control to produce an exact perceptual match.

In such a situation other criteria must apply to determine which of several possible motor plans becomes 'automatized'. It is suggested that one such criterion is likely to be that a plan which places least demand on 'down-line' components of the system is most likely to be 'adopted' for future use. That is, a plan which is simple enough to be assembled reliably and consistently on consecutive occasions by the (as yet immature) Speech Processing component, and executed reliably and consistently by the (as yet immature) Motor Execution components of the system; (that is, by the neuro-muscular systems which control the articulators). The importance of a plan being simple enough to allow **consistency** of execution is stressed, and this point is expanded below.

A second, and integrally linked criterion which governs the 'choice' of a particular motor plan is likely to be one which relates to the communicative success of the resulting spoken utterance. Feedback about the communicative success or failure of an utterance comes from the verbal responses and actions of listeners which indicate whether a child's attempted communication has been understood. This 'environmental feedback' is likely to exert a powerful influence on the 'choice' of an acceptable motor plan for an utterance. Furthermore, the determiners of communicative success of a particular output form may relate not only to closeness of match to the adult target form but also to the degree of **consistency** with which a child is able to produce the form. The significance of consistent use of a particular form in the earliest stages of speech development is self evident: in fact an infant's vocalizations are not accorded the status of 'words' or 'protowords' until a listener can identify some consistency in the characteristics of a vocalisation, whether or not it resembles an adult form, in association with a particular event or object. It can be argued that the communicative success of a child's utterances continues to depend, to some extent at least, upon the consistent use of a particular form across many attempts at a particular word and in a variety of different contexts. A listener is most likely to interpret correctly a child's utterances if the child is consistent in his realisations of particular phonemes and phoneme combinations across many lexical items; that is, if a listener can begin to identify patterns or rules in the child's output which relate the child's forms in a systematic way to adult forms.

The clinical experience of the author supports such an assertion: it is common for the parent of a child, who presents with speech which is initially unintelligible to the therapist, to report little difficulty in understanding the child. It soon becomes apparent that the child has a more or less consistent system and the parent has learned to recognise the 'rules' which relate the child's forms to adult target forms.

Thus the choice of motor plan for 'automatisation' and entry into a child's Output Lexicon is governed by both internal and external factors: ease of implementation within the current limitations of the child's speech production mechanism and hence increased likelihood of reliable and consistent execution in a variety of circumstances; the closeness of match between the resulting speech output and the adult target form, which will be judged both directly by the child via auditory feedback and as the result of environmental response; and the influence of environmental reinforcement of non-adult-like forms which relate in a systematic and consistent manner to adult target forms.

5.3.1.4. Explanation for the occurrence of simplifying phonological processes in normally developing speech.

It is the case, (as described in section 1.2.2.) that certain 'rules' relating child forms to adult target forms are very commonly identified in large numbers of normally developing children and that these same rules also seem to apply, but to persist longer, in the speech of children regarded as delayed in speech acquisition: for example, the reduction of consonant clusters to single consonants; realisation of velar consonants as alveolars, etc. Most recent research into children's phonological development has emphasised the rule governed nature of their output. Certain rules are of such widespread occurrence in the speech of developing children that they are regarded by some authors, especially Stampe (1969 & 1979), as 'universal' and 'natural' simplifying processes. How might this be explained in terms of the development of speech motor skills?

It may be that the neurophysiological development of the speech production mechanism tends to follow a common course in the majority of children and that this pattern of development favours the use of certain combinations of co-ordinative structures before the use of others; that is, that certain kinds of motor plan will be able to be implemented by the SPM of developing children before others, leading to common 'solutions' to reproducing adult forms being adopted by a majority of children. That is, 'ease of articulation' may relate directly to neurophysiological maturation which governs the number of co-ordinative structures and the complexity of combinations of actions of those co-ordinative structures which are available to the Motor Processing component of the SPM for the implementation of motor plans at a particular stage in a child's life. Thus during this gradual process of neurophysiological maturation a child must 'make do' with a limited range of available combinations of articulatory gestures; that is, the Motor Programmer must allow the range of adult phonological contrasts to be 'mapped' onto a limited set of articulatory configurations.

5.3.1.5. Variable and inaccurate realisations in normally developing speech, in relation to the development of motor skills.

Most investigations which have emphasised the rule governed nature of child speech have involved mainly single token data (and often mainly single word rather than connected speech data). The data from the current investigation suggests that in fact, as well as systematic and consistent relationships between adult target forms and children's realisations being apparent, there is also considerable **variability** in children's realisations of target forms when multiple token connected speech samples are examined. See, for example, the analysis of the tokens of the experimental phrase from subjects N8 and N9, given in Appendix 3A.

How might the occurrence of variable realisations such as these be explained in the context of developing speech motor control abilities?
In some instances variable realisations can be interpreted as evidence of a child being in the process of revision of a rule (elimination of a simplifying phonological process); that is, the child on some occasions is prompted to attempt a revised plan for an utterance which he usually realises in non-adult-like form. This kind of situation is discussed by Hewlett (1990, p32) and is referred to below. However, many of the variable realisations found in the current data seem to suggest inaccuracy or lack of control over the implementation of an assembled motor plan. That is, it is suggested that such variations of output in multiple token samples suggests a limitation at the level of Motor Execution; that is, a limitation on the amount of ongoing control which the motor execution component of the SPM is able to exert over the implementation of an assembled plan once that implementation has begun. In neurophysiological terms this may be regarded as a manifestation of immature closed loop feedback systems within the speech musculature. Such an explanation for the occurrence of variable and inaccurate productions might in turn explain the apparent trade off between speed of execution of the experimental phrase and the occurrence of imprecise realisations in

the N Group data; that is, attempted fast execution of the phrase stretches the resources for ongoing control to the point where control is lost.

5.3.1.6. Explanation for the gradual elimination of simplifying phonological processes in normal development.

This section discusses how a normally developing child might progress in his phonological acquisition as his speech motor abilities mature. That is, why and how a child gradually changes his output to achieve a closer match with the system of phonemic combinations and contrasts of the adult target language.
Again Hewlett's model can provide a basis for discussion:

> The only way that a pronunciation of a word can actually be revised is by accessing it again directly from the Input Lexicon and producing it via the slow route, that is via the Motor Programmer which devises a (partially) new motor plan for it. ...... In time, when the new motor plan has become refined and practised, its validity can be acknowledged in the input - output mapping rules, whereupon the relevant rules will be changed, bringing about a change in output lexical representations. (Hewlett 1990 p33)

What might motivate the initiation of such a revision process?
As a child develops, cognitive and meta-cognitive abilities increase and perhaps also perceptual abilities become more refined and the child is likely to become more aware of discrepancies between his speech output and the adult target language and he is more likely to be able to bring problem solving abilities to bear on the task of remedying that mismatch. Thus cognitive developmental changes tend to prompt the Motor Programmer to re-access items from the Input Lexicon and attempt to devise more satisfactory motor plans for certain specific lexical items and/or for the realisation of particular phonemes and phoneme combinations. A further motivation to attempt revisions is probably a change in the nature of the feedback which a child receives from the environment; that is, the range of listeners to whom the child's communication is addressed is likely to increase as he gets older and engages in interaction outside his immediate family, and perhaps also the expectations of family listeners tends to change as the child matures so that they tend to draw his attention either directly or indirectly to non-adult-like forms in his speech.

If maturation of speech neuromotor control has 'kept pace' with these cognitive (and environmental) changes, then newly devised, or partially revised, motor plans drawn up by the Motor Programmer, (which at an earlier stage could not have been successfully and consistently implemented by the SPM), can now be implemented using the increased resources of the Motor Processing and Motor Execution components of the system, resulting in a closer perceptual match with Input Lexicon forms and greater communicative success. As a result of the feedback mechanisms described above the revised form will in turn become automatized and a revised set of feature specifications will replace the original entry in the Output Lexicon. It is likely that revisions are first attempted for specific lexical items which have a high occurrence (high level of significance) in the child's spoken language, and a child then gradually learns that a revised motor plan for a single word or small set of words also 'works' for many other items which share some of the same phonemes or phoneme combinations; that is he gradually generalises the revised rules and gradually 'suppresses the occurrence of a simplifying phonological process'.

Thus in normally developing children, that is, those in whom development in all areas proceeds satisfactorily and in synchrony, it is possible to explain the widely observed progression towards adult like pronunciation patterns on the basis of integrated and interdependent changes in cognitive, perceptual and neuromotor abilities.

5.3.1.7. Delayed phonological acquisition in relation to speech motor development.

For some children, those labelled as phonologically delayed or disordered, the progression towards an adult phonological system is much slower and may follow an atypical course. In what way might the results of this investigation contribute to explanation of this delayed development?

If a child's coginitive and perceptual abilities are developing satisfactorily, and he is in an appropriate / adequate environment, then, as argued above, the child will be prompted from time to time to attempt revision of his output forms. However, if the child's speech motor control abilities are maturing more slowly or in a different way than in other children, when the Motor Programmer devises a new, or modified, motor plan for an utterance the plan will fail to meet the criteria which would allow it to become automatized and used to revise the entry in the child's Output Lexicon; that is, the resources available to the Motor Processing and Motor Execution components of the system will be insufficient to enable the revised plan to be assembled and executed with ease and reliability. The new plan will therefore be 'rejected' and the child will continue to employ his existing output forms. That is, a child's attempts to acquire phonetic knowledge about the gestural specifications to match perceptual forms is 'frustrated' by continuing limitations, beyond the usual age, on his speech motor production abilities. Thus, continuing immaturity of speech motor abilities can offer a possible explanation for a child's continuing use, beyond the expected age, of a restricted range of phonemic contrasts and phoneme combinations, and/or atypical or idiosyncratic non-adult-like forms: and, in the current investigation, this argument can be used to suggest a possible causative link between the delayed phonological development of the P Group subjects and those results which indicate that these children have less mature speech motor abilities than the N group of subjects.

5.3.1.8. Other possible explanations for delayed phonological acquisition.

It is, of course, possible that the opposite situation might arise in the course of child's development: that is, a child's speech motor skills might mature at the normal rate, but those developmental (and environmental) factors which underlie awareness of mismatch between child and adult forms may be inadequate or slow to develop. In such a situation the Motor Programmer is simply not prompted to attempt revisions, and the increasing potential of the child's motor speech production abilities is not put to use. That is; inadequate development of auditory perceptual abilities (and perhaps of auditory memory); slow or inadequate cognitive development including development of the 'meta' abilities involved in phonological and communicative awareness and perhaps inadequacy of environmental factors which determine the nature and amount of feedback which the child receives about the success of his communicative attempts, may all underlie a child's failure to progress in phonological acquisition.

Further possibilities should also be considered: it may be that in some children an immaturity of speech motor capacity at an early and crucial stage in speech acquisition may tend to make the child 'give up' on attempting to devise plans which will move his speech output towards the adult target system. So that even after his motor capacities have matured to adequate levels he still fails to attempt revisions of his output. That is there may be groups of children who continue to under-use their speech production capacities because of early experience of failure in the face of inadequate motor speech abilities.

Yet another possibility should be discussed: that the readiness with which a child can succeed in revising his early output forms may relate to the time at which, and the extent to which, these forms became fully automatized; that is, some children might achieve automatization of non-adult forms very early in their development and these may then be particularly resistant to change.
In section 1.5.2.2. the biochemical basis for the automatization of motor performance was discussed, and it may be that these biochemical changes occur with greater ease, and at an earlier age in some children than in others, resulting in differences in the facility with which chldren can revise their output forms.

The influence of the time and degree of automatization of output forms is emphasised by the author's clinical experience of phonologically disordered children who have almost eliminated a simplifying process after a period of therapy, but who go on using their 'old' forms for words which have been in their vocabulary longest and occur frequently in their communication, such as family or pets' names. Presumably the neural networks which assemble the plan for the action of the co-ordinative structures needed for the execution of these highly overlearned items operate with particular strength and speed and are particularly difficult to revise.

5.3.1.9. Summary of the discussion of the relationship between phonological development and speech motor maturation.

This section has explored ways of explaining various observed characteristics of normal and delayed phonological development in relation to the gradual maturation of the neuromotor skills which underlie speech production. The importance of the inter-relationships among individual differences in neuromotor development; cognitive and perceptual development and environmental factors in determining the speed and ease with which children progress in phonological acquisition has been emphasised. The writer takes the view that motor and cognitive aspects of speech acquisition cannot be separated, and would stress the influence of level of motor control skills on a child's ability to learn to produce the adult system of phonological contrasts, and also the influence of cognitive factors on a child's use of his speech production potential. That is, not only must a child be capable of assembling and executing sets of articulatory gestures, but he must be motivated to, and be capable of, engaging in a learning process to discover which particular configurations will result in a match for particular perceptual targets.

5.3.2. The investigation in relation to current therapy procedures for phonological delay/disorder.

This section examines the rationale of current therapy procedures and discusses whether the success of these procedures in promoting phonological change is compatible with the view that immaturity of speech motor control abilities is a contributory factor in phonological disability in children. The section also examines the implications of the investigation and of the discussion in the previous section for the rationale and design of intervention procedures.

A review of approaches to remediation for phonological disorder is beyond the scope of this work, but the reader is referred to Howell & McCartney 1990 for a recent account.

5.3.2.1. The rationale of recent intervention procedures.

Most current remediation approaches are based on the view expressed by Grunwell that phonological disorder is "....a neurolinguistic dysfunction at the phonological level of cortical representation and organisation of the language system" (Grunwell 1987 p200), and therefore therapy is aimed at bringing about change at that level. Of remediation approaches which take this view of phonological disorder most have utilized minimal pairs of words in therapy; that is, pairs of words in which meaning differences are signalled by a single feature difference, such as, pin/bin, sew/toe, light/like, to increase the child's understanding that sound change conveys meaning change and prompt him to reorganise his system of sound contrasts; for example, Hodson & Paden (1983) and Weiner (1981 & 1984).

The procedure with which the author has been most closely involved is an approach known as 'Metaphon' (Howell & Dean, 1991), which goes beyond other 'minimal pair' approaches by bringing together linguistic and learning theory in an intervention procedure which centres on the development of children's phonological and communicative awareness (metalinguistic abilities) in order to provide tools for effecting change in their phonological systems. In the first phase of therapy children are encouraged to explore and become aware of the nature of speech sound contrasts by making these contrasts explicit in terms to which children can relate. For example, the contrast between voiced and voiceless sounds might be represented as a noisy/quiet difference; the distinction between fricative and plosive consonants might be represented as a long/short difference. In the second phase of therapy children are encouraged to make use of this new awareness to bring about change in their speech output; that is the learning situation, which centres on conveying messages which depend upon signalling a contrast between minimal pairs of words, helps a child to become aware that his communicative attempts often fail to convey his intended message and that, using the knowledge acquired in phase one he can attempt to revise his output forms to increase his communicative effectiveness.

The success rate of this approach to remediation has been shown to be high (Hill, Howell & Waters, 1988 and Hill, Howell Waters & Dean, 1989), and the measured change in children's output following therapy is regarded as being due to cognitive level changes in which the children's knowledge of the system of sound contrasts in the language has increased as the result of therapy (phonological awareness), and children's understanding of the need to revise their output in order to improve their communicative effectiveness has been increased (communicative awareness). The rationale for this therapy procedure centres firmly on bringing about cognitive/linguistic level changes in the child and makes no explicit reference to motor aspects of speech production / acquisition. The success of such a procedure in bringing about change in children's phonological output appears to argue against the view expressed in this work that development of speech motor control and motor learning are essential underlying factors in phonological disability (and, by implication, in phonological remediation). The following sub-section explores a possible explanation for the effectiveness of the Metaphon therapy approach which is compatible with that view of phonological disability.

5.3.2.2. Phonological change in response to cognitive / linguistically based therapy.

Children's responses to such intervention procedures can be explored in terms of Hewlett's model of speech production (described in section 5.3.1.1. above). The provision of learning situations which raise awareness of lack of communicative effectiveness will in turn raise a child's awareness of mismatch between his own output forms and adult target forms and tend to prompt the Motor Programmer to reaccess items direct from the Input Lexicon and attempt to devise more appropriate motor plans. Any procedure which utilises minimal pairs of words in meaningful contexts is likely to have such an effect; but will not necessarily aid the child in his subsequent attempts to devise new motor plans.
One way in which the Metaphon approach differs from other minimal contrast approaches may be in the way that the learning opportunities provided in both phases of therapy **do** succeed in facilitating children's efforts in trying out new motor plans for an utterance. This facilitation has several aspects: in the first phase of therapy the child is encouraged, not only to listen to and categorise contrasting speech sounds but also to 'play' and 'experiment' with sound **production**; that is, he is required to attempt to produce a range of non-speech and speech sounds which fall into particular

perceptual categories, for example, noisy as opposed to quiet, long as opposed to short, etc. These activities provide the child with opportunities to experiment with, and practice, the implementation of motor plans to match particular perceptual categories of speech sound, while being provided with feedback from the therapist as to whether his productions, in her judgement, seem to fall into the relevant category. It is likely that the child, during these activities, is gradually discovering, strengthening and automatising the processing of motor plans which match particular perceptual categories of speech sounds. This gradual motor learning must depend on repeated opportunities to experience the combined auditory, proprioceptive and kinaesthetic feedback associated with particular vocal tract configurations, reinforced by external feedback from the therapist.

The second facilitating factor in the Metaphon approach, which distinguishes it from other minimal-contrast approaches depends on the nature of the feedback offered to the child in the second phase of therapy. At this stage the child and therapist take turns to convey minimally contrasting 'messages'. When the therapist is in the 'speaker' role the child hears the adult forms of the target words and is encouraged to discuss the contrast between them, helping to maintain high awareness of the nature of the difference between the pair of words. When the child is in the speaker role his awareness of the **need** to signal a contrast is high and he (usually quite quickly) realises that his experimentations in the earlier phase of therapy are relevant to this need and begins to attempt to change his output forms in order to signal the required contrast. At this stage a child is not always successful in achieving a fully adult-like contrast; but the therapist responds positively to **any** evidence that the child is attempting revision of his habitual output forms; that is, the therapist will provide graded feedback to the child, essentially about the partial or complete **communicative** success of his attempts, which encourages the child to make further attempts which move closer to the target forms and then become more and more automatic in their implementation. Thus at both phases of therapy a child is provided with opportunities for experimentation and gradual learning about the articulatory specifications which signal the meaningful contrasts of the language. I therefore argue that such an approach to therapy, though seen as targeting a cognitive /

phonological rule system level of organisation, is in fact also (and perhaps essentially) providing learning opportunities for experimenting with (and receiving feedback about) the implementation of motor plans which successfully signal meaningful contrasts. That is, the success of a treatment procedure such as Metaphon is entirely compatible with the view that development of immaturity of speech motor (phonetic) abilities is an underlying factor in phonological disability.

5.3.2.3. Factors which may affect children's progress in therapy.

It will be recalled that in section 5.3.1. it was suggested that some phonologically delayed children may have on-going limitations on their speech motor abilities while others, at the time of presenting for therapy may be under-using their speech motor potential for a variety of reasons.
The most rapid and ready progress might be expected in children who, at the time of commencing therapy, have little or no limitation on their speech motor skills; that is, children who are under-using their speech motor abilities for one or more of the reasons discussed section 5.3.1.8. above. In such children participation in a therapy procedure such as Metaphon rapidly increases their awareness of the need for change and provides the tools for effecting that change. Undoubtedly such a child still requires opportunities for motor learning (for trying out and automatizing newly devised plans), but this motor learning takes place rather rapidly and 'easily'; that is, the child needs only to be prompted to make use of his speech production potential and to be provided with facilitating learning situations and he will be able to effect change in his output and in the rules which map his output lexicon forms to the adult forms in his input lexicon.

On the other hand, children who, at the time of commencing therapy, are still significantly immature in speech motor abilities may progress less readily in therapy because, although therapy succeeds in raising awareness of the need for change, their attempts at trying out new motor plans are frustrated by continuing neuromotor limitation. Such children may achieve ready success in those parts of the therapy procedure which involve demonstrating awareness of speech sound contrasts; that is, all stages in which the child is the listener rather than the speaker; but he is likely to require more, and perhaps different kinds of, opportunities for sensori-motor exploration, experimentation and automatisation before he can participate successfully in the speaker role in either phase of the therapy procedure.

An ongoing study (Anderson, forthcoming, and Dean, Anderson & Waters, in preparation) which uses Metaphon therapy with small groups of young children with phonological disabilities has, in fact, revealed two distinct patterns of response to therapy: some children progressed without difficulty through all stages of therapy while others found it difficult to participate in the 'speaker' role at any level and required additional and more specific motor learning opportunities. It must be emphasised that all the children in Anderson's study were classified, by referring therapists, as phonologically disordered, but on the basis of differential response to therapy Anderson regards the second category of children as having ongoing motor constraints on their phonological development and on their ability to progress in therapy.

It is worth speculating that children whose speech sound acquisition difficulties, and lack of progress in therapy, are regarded as the result of 'immature articulatory praxis' (Milloy, 1986), 'developmental articulatory dyspraxia' (Milloy, 1986 and Milloy & Morgan-Barry, 1990) or 'developmental verbal dyspraxia' (Stackhouse, 1992) may represent the extreme of a continuum of developmental speech motor control / planning deficits. Milloy (1986) regards 'developmental articulatory dyspraxia' as a condition resulting from a neurological deficit which affects the "establishment of the sensory feed-back loop systems required to control and contribute to the automaticity of the motor skills necessary for the production of precise articulatory placements". Stackhouse, on the other hand, suggests that " 'dyspraxia' has become an umbrella term for children with persisting and serious speech difficulties in the absence of obvious causation, regardless of the precise nature of their unintelligibility" (Stackhouse, 1992, p30). Stackhouse & Snowling (1992), in a longitudinal study of two school-aged children classified as having developmental verbal dyspraxia, identify a combination of deficits including problems with speech motor programming and co-ordination, auditory processing and 'lexical development'. It may be that evidence which points to the importance of sensori-motor maturation and learning both in normal and in delayed/disordered phonological acquisition can offer some insight into the relationship between phonological disorder and 'developmental articulatory dyspraxia'. That is, acknowledgement that **all** phonological acquisition involves an interplay of factors which include 'input' factors of auditory perception and processing and 'output' factors of neuromotor planning, co-ordination and control, may make it unnecessary to postulate distinct underlying causations for phonological disability and developmental articulatory dyspraxia.

5.3.3. The results in relation to theories of speech timing.

As outlined in Chapter One the issue of the specification and control of speech timing in mature speech is by no means resolved. Areas of continuing uncertainty and controversy include whether timing phenomena depend on one or several control mechanisms and whether these mechanisms are central or peripheral in the speech production process and whether they are extrinsic to the motor implementation of speech or intrinsic to speech motor organisation. This section discusses what explanatory power these various theoretical positions might have in relation to the results of the current investigation.

5.3.3.1. Theories of speech timing in relation to the results of the measures of temporal variability.

In an intrinsic theory of speech timing both temporal and spatial aspects of articulation are regarded as direct consequences of the dynamic activity of embedded systems of co-ordinative structures (see section 1.5.1.3.). Hence the greater temporal variability found in the speech of young children compared with adult speech would be regarded as a consequence of the relative unreliability and imprecision of the integration of the movements controlled by a particular co-ordinative structure or embedded set of co-ordinated structures in child speakers. That is, the high level of temporal variability observed in children's speech is a consequence of immaturity of dynamic integration and control in the muscle synergisms which are responsible for articulatory movement. The precision and consistency with which the movements associated with the operation of co-ordinative structures are integrated must, in turn, depend on the speed, amount and reliablity of the information provided about the relative positions and velocities of the various articulators involved by closed loop feedback circuits within the muscle synergisms. That is, an intrinsic theory of speech timing is compatible with the view that high level of temporal variability is directly related to immature neuromotor development.

In contrast, extrinsic theories of speech timing, which presume some extrinsic clocking device which regulates the intervals between events does not suggest a direct explanatory link between high temporal variability and immaturity of neuromotor co-ordination and control. As is emphasised by the following quotation, it is difficult to posit a physical basis for such an extrinsic clocking device;

> It has never been clear how the speech system could keep track of time, at least peripherally, because there is no known afferent basis (such as time receptors) for time-keeping in the articulatory structures themselves.
> (Kelso, 1987, quoted in Kelso & Tuller, 1987, p 218).

That is, since there is no feedback mechanism for time as a separate aspect of speech production, and no known physical basis for an extrinsic clocking mechanism, it is difficult to explain why temporal control should be poorer in young children than in adults. That is, if a clocking device operates independently of afferent feedback and therefore does not depend upon the maturation of neurological feedback mechanisms it might be expected that temporal variability would be equally low at all ages.

Intrinsic timing theory also seems more able to offer an explanation for the finding in the current investigation that in young children's speech (but not in adult speech) temporal variability tends to be higher when fast execution of utterances is attempted. It is generally accepted that overall speed of utterance is a distinct aspect of speech timing which is, or at least can be, under conscious control (see section 2.2. where investigations involving manipulation of speaking rate in response to instructions were described). It was suggested, in section 3.6.2.3., that adults tend to adopt speeds which allow optimum precision and control of temporal relationships, whereas young child speakers are less aware of the need for, and possibility of, 'choosing' an optimum speed of utterance, and may attempt to execute speech at speeds which over-stretch their neuromotor resources, resulting in lack of precision in the control of temporal relationships.

Young children's lack of ability to maintain control over timing relationships at fast rates of utterance might be explained by inability of the feedback mechanisms within and between co-ordinative structures to provide information fast enough about the relative positions and velocities of the articulators to regulate precisely the relevant muscle contractions in relation to one another): such a

view is compatible with an intrinsic theory of speech timing.
As pointed out in section 1.4., research which aims to compare normal and speech delayed/disordered children on measures which reflect the operation of speech feedback/control mechanisms, seems likely to be a fruitful line of investigation. See, for example the bite-block study involving normal and phonologically disordered children (Edwards J., 1991), described in section 1.4..

5.3.3.2. Theories of speech timing in relation to the results of the speech rate measure used in this investigation.

The view expressed in intrinsic speech timing theory, that temporal relationships are a direct consequence of the integrated dynamic actions of embedded sets of muscle synergisms, and therefore of the neuromotor control mechanisms which regulate those muscle systems, must lead to the conclusion that the **number** of dynamic articulatory manoeuvres which can take place in a measured time will depend upon the level of maturity of those neuromotor control mechanisms, that is, is compatible with the view, expressed in this thesis, that fewer articulatory gestures per unit time suggests less mature speech neuromotor control.

A child who is limited in the number of co-ordinated dynamic articulatory manoeuvres which can be performed in a given time has at least two options open to him: his speech production mechanism may accept and automatize output forms which are structurally simplified compared with adult target forms, and/or he may adopt a slow speed of execution of speech which may, to some extent, lessen the need to reduce phonological structure. The adoption of the latter strategy might imply a more conscious awareness of a need to reproduce accurately the target phonological structure of an utterance and more awareness of the possibility of exercising voluntary control over speed of utterance.

There is evidence in the current data of both these strategies among the phonologically delayed children. For example, subject P5 exhibited a consistently slow speed of execution in all tokens of the phrase. His phrase durations ranged from 2130 -2570 ms, mean 2312 ms, which made him the slowest speaker among all the subjects. This child **also**, in common with the other P Group subjects, exhibited structural reductions of the phrase but he exhibited the **lowest** occurrence of structural reduction among all the P Group subjects (see section 4.4.2.). It is possible that this child had a particularly high awareness of the possibility and advantages of controlling speed of execution to off-set his speech motor limitations.

Subject P7, on the other hand, seemed to exercise little control over speed of execution of the phrase, which was fast and very variable: this child's tokens were characterised by high occurrence of structural reductions and imprecise/undershot articulation of segments.

Intrinsic theory of speech timing which stresses that temporal relationships of speech are consequent on the operation of the neuromotor mechanisms which underlie speech production is in accord with the view expressed in this thesis that slower speech rates (in terms of number of segments produced per unit time) are indicative of less mature speech neuromotor control.

5.4. CRITICAL EVALUATION OF THE INVESTIGATION

In this section particular aspects of the design are identified which have resulted in difficulties in the conduct of the investigation or which have placed constraints on the interpretation of results.

5.4.1. Age of the child subjects

The child subjects were all of pre-school age.
With hindsight, the choice of such a young age range was disadvantageous in several respects: considerable care and ingenuity was necessary in the choice of materials and in the design and management of the data collection procedure; and it often proved difficult to obtain good quality recordings from such young children who did not understand the importance of maintaining a constant distance from the microphone.
A further, and more important, consequence of the young age range of the child subjects was that much of the speech data from the normal child group was not adult-like in phonological form. This was, of course, expected in the P Group data but the extent of occurrence of non-adult-like and variable realisations of the experimental phrase in the N data had not been fully anticipated. This in fact allowed

some interesting and largely unforseen comparisons to be made in the perceptual analysis of the data from the two child groups. However the fact that the normal child group in the investigation had not yet achieved full mastery of the speech sound system of the language has lead to some uncertainty in the interpretation of the results: in particular in the interpretation of the measures of temporal variability. It would therefore be interesting to conduct a similar experiment with an older age range of children.

5.4.2. Choice of instrumentation for acoustic analysis.

The instrumentation used in the investigation (described in section 1.2.3.1.) did not allow sections of the auditory signal to be heard as the visual display of the signal was being segmented. Such a facility would probably have enabled the temporal acoustic measurements to be made with greater accuracy.

5.4.3. Choice of segmental measures

The choice of segments for VOT measurements was not ideal; that is, interpretation of the results of VOT measures would have been more straight-forward if VOTs for voiced and voiceless targets in similar phonetic environments had been examined: for example, if VOT measures had been made for voiced and voiceless bilabial plosive targets which both occurred as single word-initial consonants in stressed syllables and succeeded by vowels of similar quality and length. With hindsight, the author is aware that the choice of experimental phrase, which was chosen primarily to interest and motivate the child subjects, did not give sufficient consideration to the phonetic context of the segments which were to be the focus of acoustic analysis.

Time constraints necessitated that, because of the large number of tokens of the experimentl phrase involved (648 in total), temporal acoustic measurements could be undertaken only for selected segments of the experimental phrase. However, the selection of only six segmental measures from the phrase (which consisted in most adult tokens of 17 or 18 distinct speech segments) prevented any overall conclusion as to how the adults achieve relatively short phrase durations in relation to child subjects; that is, whether particular segments of the phrase are spoken by adults with particularly short duration compared to child subjects or whether all segments of the phrase exhibit shorter durational values. In particular, the inclusion of only one vowel duration measure (especially since this was a diphthong in all adult realisations) prevented any conclusion as to whether vowel durational characteristics might develop differently from consonant durations. (See discussion in section 3.6.2.2.). It would, therefore be of value to conduct a similar experiment involving fewer subjects (and therefore fewer tokens) in which all segments of an experimental phrase could be included in the temporal acoustic measurement.

5.5. DIRECTIONS FOR FUTURE RESEARCH.

This section gives several outline suggestions, in the light of the current investigation, for future research in the area of speech motor abilities in normal and phonologically delayed children.

5.5.1. Investigation of temporal variability in older normal and phonologically delayed/disordered children.

This proposal arises from the results of the current investigation which showed significant differences between the adult subject group and the child subject groups on all measures of temporal variability in multiple token speech samples, but no significant difference between the normal and phonologically delayed child groups. The suggestion was made in section of 5.3.2. that the lack of difference between the two child groups may have been a consequence of the very young age range of the subjects who were all still in the process of acquiring control over the essential meaning-carrying aspects of speech production.

An investigation is proposed to evaluate this possibility in which a group of normal children whose output phonology is fully adult-like (on the basis of assessment and analysis and the judgement of listeners trained in phonological analysis) and a group of children of the same age who are still experiencing difficulties in phonological acquisition. It is likely that the optimum age range would be approximately 6 - 7 years, at which age it should be possible to find normal children who satisfy the above criterion and

also children with phonological disability who are functioning at an age-appropriate level in other aspects of langauge development.
A data collection procedure similar to that used in the current investigation would probably be appropriate, with some adaptation of the content of experimental phrases and style of illustration.

5.5.2. Further comparisons of normal and phonologically disordered children on speech rate measures.

The measurement of rate of speech motor performance is of prime importance in the investigation of the status of speech motor abilities. In the current investigation a new measure of speech rate was used which took account of subjects' realisations of the experimental utterance and significant difference in speech rate was found between the P and N groups of child subjects in multiple token speech samples of a particular experimental phrase. It is proposed that this type of measure should now be repeated with further groups of normal and phonologically delayed children using multiple tokens of different experimental utterances to discover whether the results of the current investigation can be replicated.
It is also suggested that measurement of rate of speech motor performance using a measure of segments/s could be extended to spontaneous speech data, although the length of utterance factor would have to be taken into account since length of utterance is known to affect speech rate (Slis, Haselager & Rietveld 1988, discussed in section 2.3.).

In section 5.2.1.1. reference was made to measurement of speech rate in terms of **syllables** per unit time on data from some of the child subjects in the investigation. It was pointed out in that section that since the experimental phrase consisted of only eight syllables spoken over a time span in the order of 1 or 2 seconds, a measure of speech rate in syllables /second was bound to result in a very narrow spread of values making comparisons between subjects of limited value.

It is therefore proposed that in a further investigation of speech rate, longer experimental utterances should be selected, so that comparison between inter-group differences of syllable-rate and segment-rate can be made. (The use of longer utterances would probably place a constraint on the lower age limit of child subjects.)

5.5.3. Comparison of the effects of experimental manipulation of speaking rate (speed of execution) in normal and phonologically delayed children.

In section 2.3. a study by Smith, Sugarman & Long (1983) was described which undertook experimental manipulation of speaking rate in adults and in normal child speakers from the ages of 5 to 9 years. That investigation showed, firstly, that these normal children could modify their speed of execution of utterances in response to instructions, and, secondly, that temporal variability was affected by this modification of speaking rate. The investigation suggested that the apparent effects on temporal variability of subject's manipulation of speaking rate depended upon the way in which temporal variability was measured; that is, that relative variability of **phrase** duration tended to be lowest at fast speeds of utterance, whereas the relative variability of selected **syllable** durations was found to be lowest when subjects employed their preferred (habitual) speeds. An investigation is suggested to determine whether phonologically delayed children are also able to manipulate their speed of execution of utterances in response to instructions, and if so, whether conscious modification of speed has similar effects on measurements of phrase, syllable and segmental temporal variability in normal and phonologically delayed children.

Smith, Sugarman & Long's investigation does not report whether manipulation of speaking rate had any effects on the phonological form of subjects' tokens of experimental phrases, and , in the light of the results of the current investigation which suggest that short mean phrase durations (fast speed of execution) tend to be associated, in the child data, with high occurrence of structural reductions and of non-adult-like segment realisations, it would be of interest to determine whether effects on phonological accuracy of instructions to employ faster speeds of execution differ in normal and phonologically delayed children.

5.5.4. Investigation of the relationship between level of maturity of speech motor abilities and response to therapy.

In sections 5.3.2.3 - 5.3.2.4. it was suggested that, although all phonologically disordered children probably require opportunities for motor experimentation and learning in therapy, it may be that some children, in whom limitation on speech motor skills is still, at the time of therapy, a major constraint, may require more explicit and structured help in discovering articulatory (motor) configurations to match perceptual targets.

If the results of the measures of speech rate (taking account of phonological form) in the current investigation can be replicated with other subjects and other experimental utterances, a further step might be to conduct an investigation to determine whether such speech rate measures have predictive power for response to therapy. That is, whether the measure might identify those phonologically disordered children who will require the most extensive and explicit help with motor learning.

5.5.5. Investigation of the relationship between speech rate (as measured in this investigation) and performance on speech DDK tasks.

A number of investigations of children's DDK rates were discussed in section 1.1.2., and a recent investigation by Henry (1990), in which significantly slower DDK rates were found in a group of 'severely speech disordered' child subjects compared with a group of normal subjects, was of particular interest.

It is suggested that it would be of clinical relevance to investigate degrees of correlation between measures of mean speech rate in multiple-token connected-speech samples (including both segment rate and syllable rate) from normal and phonologically disordered children, and DDK rate scores over sequences of varying complexity. (Such an investigation would necessitate clarification of the questions raised by Henry's investigation regarding the criterion of measurement of DDK rates in relation to the phonological accuracy of the repeated sequences.)

5.6. SUMMARY AND CONCLUSIONS

This section gives a brief resume of the investigation and states conclusions drawn on the basis of the results.

5.6.1. Purpose and design of the investigation.

The main issue addressed in this work has been that of the relationship between children's phonological development and the development of speech motor co-ordination and control. The thesis has reported an investigation designed to test the hypothesis that speech motor co-ordination and control is less mature in pre-school children classified as phonologically delayed than in children of the same age who are developing speech normally, and that immaturity of speech motor control and co-ordination is implicated in phonological disability in children.

The hypothesis has been tested by means of a two-phase investigation involving temporal acoustic (spectrographic) measurements and perceptual analysis of multiple token speech samples from three groups of subjects.

The first phase of the investigation compared data from a group of 12 adult speakers with data from a group of 12 normally developing pre-school children, and the second phase examined data from 12 phonologically delayed pre-school children in the light of the results of the first phase. In particular, the results of the first phase of the investigation were used to formulate three specific experimental hypotheses which were tested in the second phase: (i) phonologically delayed subjects would exhibit higher levels of temporal variability in multiple token speech samples than normally developing child subjects; (ii) P Group subjects would exhibit longer group mean durations on durational measures which had been found to be significantly longer in the N Group than in the adult group, and (iii) speech rates (on a measure which takes account of the phonological structure of the data) would be slower in the phonologically delayed child group than in the normal child group.

5.6.2. Results of the first phase of the investigation

The results of the temporal acoustic analysis in the first phase of the investigation were broadly in agreement with the results of previous studies; that is, the normal child subject group exhibited significantly higher levels of temporal variability than adult speakers; longer mean phrase durations and (in the main) longer mean segment durations than adults. Further analyses of the results of these temporal acoustic measures emphasised the differences between the two subject groups in their ability to maintain control of temporal precision: that is, child subjects were, in general, significantly less precise in their speech timing control when compared with adults who exhibited similar mean phrase durations; and there was a tendency in the child subjects group, but not in the adult group, for fast execution of the phrase (short mean phrase duration) to be associated with high levels of temporal variability.

Perceptual analysis of the phonological form of the data from the adult and normally developing child group showed a marked contrast between the two groups in terms of the accuracy and consistency of reproduction of the phonological form of the target phrase; that is, the child data exhibited many examples of adult-like structural reductions (connected speech forms) but also widespread occurrence of non-adult-like structural and systemic simplifications of the target phrase and widespread occurrence of imprecise and undershot articulations of segments. This suggested that it is essential to take account of, and report on, phonological structure when making acoustic measurements of speech data from young children.

The measure of speech rate which took account of the phonological structure of each subject's data resulted in a more highly significant difference between the adult and child subject groups than had been found for the mean phrase duration measure, again confirming the necessity of considering the phonological structure of children's speech data.

5.6.3. Results of the second phase of the investigation.

Of the three specific experimental hypotheses tested in the second phase of the investigation one was refuted by the results; that is, with one exception, there was no significant difference between the P and N groups on measures of temporal variability. A possible explanation for this result has been explored (see section 2.2. above). The hypothesis that phonologically delayed children would exhibit longer mean durations on measures which had distinguished between adult and normal child subjects was partially supported by the results, although group differences did not reach statistical significance: the results of the VOT measures could be regarded as supporting the main hypothesis, (see section 4.6.2.2.). The third experimental hypothesis, that phonologically delayed children would exhibit significantly slower speech rates on a measure which took account of the phonological form of the data was strongly supported by the results.

Perceptual analysis of the P Group data, when compared with the analysis of the N Group data from phase 1, gave results which were compatible with the view that the phonologically delayed child subjects were more limited in their speech production capacities than the N subjects (see section 4.6.2.5. and section 5.2.1.3.).

5.6.4. Conclusions

5.6.4.1. Conclusion in relation to the main hypothesis.

When all the results of the investigation are considered together the weight of evidence supports the view that speech motor co-ordination and control was less mature in the phonologically delayed child subject group than in the normal child subject group, although the results of measures of temporal variability in the second phase of the investigation must be regarded as qualifying this view.

The author therefore concludes that the main hypothesis, that speech motor control and co-ordination is less mature in phonologically delayed pre-school children than in their normally decveloping peers, is partially supported by the investigation.

5.6.4.2. Conclusions on the relationship between speech motor development and phonological development.

Throughout the thesis (in particular in sections 1.6. and 5.3.1.) there has been discussion of the relationship between maturation of speech motor skills, that is, maturation of neuromotor co-ordination and control over the organisation and action of the muscle synergisms involved in speech production, and phonological acquisition. The author concludes that regarding the gradual maturation of speech motor skills as an important factor in the gradual acquisition of phonological contrasts has strong explanatory power for the speech patterns observed in normally developing children and in children classified as phonologically delayed or disordered, and that increase in speech motor production capacity interacts with other developmental changes and with environmental factors to bring about gradual change in children's speech output.

5.6.4.3. Conclusions on implications for therapy.

In current intervention procedures, the extent to which change in children's phonology is facilitated by the provision of opportunities for motor experimentation, discovery and learning may have been underestimated: acknowledgement in the rationale of intervention procedures that phonological change must involve learning at a phonetic (speech motor production) level could further increase the effectiveness of therapy.

5.6.4.4. Conclusions in relation to theories of speech timing.

In section 5.3.3. above, there was discussion of the results of the investigation in relation to theories of speech timing. It was concluded that the intrinsic theory of speech timing in which the temporal relationships of speech are regarded as directly consequent upon the actions of co-ordinative structures of muscle synergisms is compatible with the results of the investigation and compatible with the view that the temporal differences found between the adult and child speech data are the result of differences of neuromotor control in these co-ordinative structures.

5.6.4.5. Conclusions on the use of temporal acoustic measurements in the study of speech motor control in young children.

The occurrence of connected speech forms in the adult data and the great diversity and inconsistency of phonological form in the child speech data, lead to the conclusion that it is essential to analyse and report precise realisations of experimental utterances in studies which use temporal acoustic analysis to evaluate maturity of speech motor control.

The results of temporal variability measures which, with one marginal exception, showed no significant difference between P and N Group subjects may mean that measurements of temporal variability cannot reveal differences in level of maturity of speech motor control among children who are still in the process of acquiring control over the essential meaning carrying aspects of speech production (see section 5.2.2. above). Evaluation of this possibility, however, must await the results of a further investigation with older child subjects.

APPENDIX 1A

SIMPLIFYING PHONOLOGICAL PROCESSES

EXHIBITIED BY

THE NORMALLY DEVELOPING CHILD SUBJECTS

(The occurrence of simplifying phonological processes was analysed on the basis of subjects' responses to the Edinburgh Articulation Test pictures and additional connected speech data.)

SUBJECT N1 (EAT Standard Score - 110)

Simplifying phonological processes:	**Examples:**
Gliding of liquids (in clusters)	Christmas -> [kwɪsmʌs]
Palato-alveolar fronting (in affricates)	Chimney -> [tsɪmni]
Backing of interdental fricatives (in word medial position)	Birthday -> [bɜɹsde] Feather -> [fɛzʌ̃r]
Fronting of interdental fricatives (in word initial and word final positions)	Teeth -> [tif] Thumb -> [fʌm]

SUBJECT N2 (EAT Standard Score - 141+)

Simplifying phonological processes:	**Examples:**
Gliding/frication of /r/ (in clusters)	Train -> [tʃjen] String -> [stjɪŋ]

SUBJECT N3 (EAT Standard Score - 103)

Simplifying phonological processes:	**Examples:**
Simplification within the sound classes liquids and glides	Queen -> [klin] Clouds -> [klaʊdz] Christmas -> [klɪsmʌs] Red -> [lɛd]
Backing of interdental fricatives (in word medial and word final positions)	Birthday -> [bɜrsde] Feather -> [fɛzʌ̃r] Teeth -> [tis]
Fronting of interdental fricatives (in word initial position)	Thumb -> [fʌm]

SUBJECT N4 (EAT Standard Score - 127)

Simplifying phonological processes:	**Examples:**
Fronting of interdental fricatives (in word initial and word medial positions)	Three -> [fri] Birthday -> [bɜrfde]
Fronting of velar nasals (one instance only)	String -> [strɪn]
Lateralisation of voiced interdental fricative (in word medial position)	Feather -> [fɛlʌ]
Fronting of labio-velar approximant /w/ (one instance only)	Wings -> [ʋɪŋz]

SUBJECT N5 (EAT Standard Score - 116)

Simplifying Phonological Processes:	**Examples:**
Vowel insertion in clusters (one only)	Flower -> [fəlaʊwə]
Fronting of interdental fricatives	Thumb -> [fʌm] Teeth -> [tif] Feather -> [fɛvɚ]
Affrication of stops in clusters (one instance only)	Train -> [tˢɹen]

SUBJECT N6 (EAT Standard Score - 129)

Simplifying phonological processes:	**Examples:**
Stopping in nasal clusters (one instance only)	Chimney -> [tʃɪmdi]
Fronting of interdental fricatives	Thumb -> [fʌm] Teeth -> [tif] Three -> [fri]
Lateralisation of voiced interdental fricative in word medial position	Feather -> [fɛɬʌr]

SUBJECT N7 (EAT Standard Score - 119)

Simplifying phonological processes:	**Examples:**
Fronting of palato-alveolars	Fish -> [fɪs] Sugar -> [sugʌr] Matches -> [matsəz̥]
Reduction of word medial clusters,	Toothbrush -[tuθbʌs] Chimney -> [tʃɪmi]
Reduction of initial stop+approx. clusters (one instance only)	Bridge -> [bɪdz̥]
Glide /liquid simplifications	Garage -> [gawɪdz] Yellow -> [wɛlʊ]

SUBJECT N8 (EAT Standard Score - 141)

Simplifying phonological processes:	**Examples:**
Fronting of interdental fricatives (in word initial and medial positions)	Thumb -> [fʌm] Three -> [fri] Birthday -> [bɜrfde]
Lateralisation of voiced interdental in word medial position	Feather -> [fɛlə]
Simplification of 3-element cluster	String -> [sfwɪŋ]

SUBJECT N9 (EAT Standard Score - 117)

Simplifying phonological processes:	**Examples:**
Gliding	Train -> [twen] Red -> [wɛd] Garage -> [gəwɪdʒ]
Affricate simplification (in word final and medial positions)	Matches -> [maʃəz] Watch -> [wɒʃ]
Fronting of interdental fricatives	Three -> [fwi] Thumb -> [fʌm] Teeth -> [tif]
Lateralisation of voiced interdental fricative in medial position	Feather [fɛlə]
Medial cluster reduction (one only)	Chimney -> [tʃɪni]

SUBJECT N10 (EAT Standard Score - 103)

Simplifying phonological processes:	**Examples:**
Glide /liquid simplifications	Red -> [wɛd] Glove -> [gɹʌv] Clouds -> [kwaʊdz̥]
Affricate simplification	Chimney -> [ʃɪmni]
Fronting of interdental fricatives	Thumb -> [fʌm] Teeth -> [tif]
Voiced interdental fricative -> approx. (in word medial position),(one only)	Feather -> [fɛɹʌ]
Fronting of palato-alveolars (word medial and final affrics. only)	Watch -> [wɒts]

SUBJECT N11 (EAT Standard Score - 139)

Simplifying phonological processes:	**Examples:**
Fronting of interdental fricatives	Thumb -> [fʌm] Three -> [fri] Teeth -> [tif] Birthday -> [bɜrfde]
Lateralisation of voiced interdental fricative in word medial position (one only)	Feather -> [fɛlʌ]

SUBJECT N12 (EAT Standard Score - 125)

Simplifying phonological processes:	Examples:
Affricate simplification	Matches -> [maʃəs]
Fronting of interdental fricatives	Thumb -> [fʌm] Teeth -> [tif] Three -> [fri]
Backing of interdental fricative (in word medial position) (one only)	Birthday -> [bɜrsde]
Gliding in clusters (one only)	Flower -> [fwaʊwʌ]
Coalesence of features in clusters (one instance only)	Sleeping -> [sɬipɪn]
Reduction of medial clusters	Soldier -> [soʊdʌ] Umbrella -> [ʌmbɛlə]
Stopping of fricative (one instance only)	Glove -> [glʌb]
Frication of approximant (one only)	Red -> [ʒɛd]

APPENDIX 1B

SIMPLIFYING PHONOLOGICAL PROCESSES

EXHIBITED BY

THE PHONOLOGICALLY DELAYED CHILD SUBJECTS

(The occurrence of simplifying phonological processes was analysed on the basis of subjects' responses to the Edinburgh Articulation Test pictures, additional pictures and objects and additional connected speech data.)

SUBJECT P1 (EAT Standard Score - 61)

Simplifying phonological processes:	**Examples:**
Stopping of fricatives	Zip -> [dɪp] Washing -> [wɒdɪŋ] Grass -> [gad]
Stopping of affricates	Garage -> [galad] Chimney -> [dɪmni]
Voicing of word initial voiceless stops	Pen -> [bɛn] Toe -> [do]
Reduction of word initial consonant clusters	Sledge -> [lɛd] Drum -> [dʌm] Snake -> [nek]
Glide /liquid simplifications	River -> [lɪvʌ] Red -> [lɛd]

SUBJECT P2 (EAT Standard Score - 59)

Simplifying phonological processes:	**Examples:**
Fronting of velars (in word final position)	Sock -> [dɔt] Leg -> [lɛd] Wing -> [wɪn]
Stopping of fricatives	Zoo -> [du] Sun -> [dʌn] Vase -> [bad]
Stopping of affricates (in word final and medial positions)	Match -> [mat] Sledge -> [s͡ɛlɛd]
Reduction of word intial consonant clusters	Grass -> [dat] Smoke -> [mok] Spoon -> [bun]

(SUBJECT P2 -continued)

Gliding of liquids	River -> [wɪvʌ]
Fronting of interdental fricatives	Path -> [paf] Thunder -> [fʌndʌ]

SUBJECT P3 (EAT Standard Score - 48)

Simplifying phonological processes:	**Examples:**
Deletion of word initial voiceless consonants (except /p/) (Sometimes glottal replacement)	Sock -> [ɔk] Tap -> [ʔap] Foot -> [uk]
Voicing of word initial /p/	Pen -> [bɛn]
Reduction/deletion of word initial fricative+consonant clusters	Sleeve -> [iv] Spoon -> [bɑn] Story -> [gɔɹi]
Backing of alveolar stops	Foot -> [uk] Door -> [gɔ]
Fronting of alveolar & palato-alveolar fricatives	House -> [ʌuf] Washing -> [wɔfɪn]
Stopping of (voiced) affricates (in word initial position)	Jam -> [gam]
Glide/liquid simplification (in word initial position)	Red -> [wɛg] Leaf -> [wif]

SUBJECT P4 (EAT Standard Score - 68)

Simplifying phonological processes:	**Examples:**
Stopping of fricatives (in word initial position)	Zip -> [dɪp] Fish -> [bɪʃ]
Stopping of affricates (in word initial position)	Chair -> [dɛʌ] Jam -> [dam]
Reduction of word initial consosnant clusters	Plane -> [ben] Drum -> [bʌm] Spoon -> [bʉn] Sky -> [dae]
Voicing of word initial voiceless stops	Pen -> [bɛn] Car -> [gaɚ]
Glide/liquid simplifications	Leaf -> [wif] River -> [wɪvʌ]

SUBJECT P5 (EAT Standard Score - 56)

Simplifying phonological processes:	**Examples:**
Deletion of word initial fricatives and liquids	Sock -> [ɔk] Zip -> [ɪp] Fish -> [ɪt] Leaf -> [it] Red -> [ɛd]
Stopping of fricatives (in word final position) (Often a double stop)	Leaf -> [it] Fish -> [ɪtʰtʰ] Grass -> [datʰtʰ] Path -> [batʰtʰ]
Stopping of affricates	Chair -> [tʰeə] Jam -> [dam] Match -> [matʰtʰ]

(SUBJECT P5 - continued)

Fronting of velars (in word initial position)	Car -> [t̪ʰa] Gun -> [dʌn]
Voicing of word initial voiceless stops	Tap -> [dap] Pen -> [bɛn]
Reduction of word initial consonant clusters	Pram -> [bam] Tree -> [ti] Sleeve -> [it] Snow -> [no] Spoon -> [pʉn]

SUBJECT P6 (EAT Standard Score - 82)

Simplifying phonological processes:	**Examples:**
Stopping of affricates (in word initial position)	Chair -> [dɛə] Jam -> [dam]
Fronting of palato-alveolars	Fish -> [wɪs] Watch -> [wɒts] Measure -> [mɛzʌ] Shop -> [sɒp]
Voicing of word initial voiceless stops	Pen -> [bɛn] Tap -> [dap]
Reduction of word initial consonant clusters	Sleeve -> [siv] Tree -> [di] Plane -> [pen] Cross -> [dɔs]
Glide/liquid simplifications	Red -> [jɛd] River -> [wɪvə] Letter -> [jɛdə]

SUBJECT P7 **(EAT Standard Score - 67)**

Simplifying phonological processes:	**Examples:**
Fronting of velars	Car -> [t̪a]
	Bag -> [bad]
	Gun -> [dʌn]
Deletion of word initial fricatives	Zip -> [ɪp]
	Fish -> [ɪtʃ]
	Sun -> [ʌn]
Stopping of fricatives (in word final position)	Path -> [bat]
	Leaf -> [ʋip]
	Nose -> [nod]
Stopping of affricates	Chair -> [tɛə]
	Jam -> [dam]
Voicing of word initial voiceless stops	Pen -> [bɛn]
Reduction of word initial fricative+consonant clusters	Thread -> [vɛd]
	Sweet -> [wit]
	Snake -> [net]
	Skip -> [dɪp]
Glide/liquid simplifications	Yoyo -> [lolo]
	Letter -> [wɛtʌ]
	Lamb -> [wam]

SUBJECT P8 (EAT Standard Score - 73)

Simplifying phonological processes:	**Examples:**
Fronting of velars	Bag -> [bad] Car -> [da]
Fronting of palato-alveolars (in word final position)	Fish -> [wɪs]
Stopping (other simplification of manner) of fricatives (in word initial position)	Sunny -> [dʌni] Shop -> [dɒp] Zip -> [dɪp] Foot -> [wʊt]
Stopping of affricates (in word initial position)	Chair -> [dɛə] Jam -> [dam]
Voicing of word initial voiceless stops	Pen -> [bɛn]
Reduction of word intial consonant clusters	Glass -> [gas] Smoke -> [mot] Snake -> [ne] Spoon -> [bʉn]
Deletion of word initial liquids and glides (except /w/)	Red -> [ɛd] Letter -> [ɛdʌ] Yoyo -> [olo]

SUBJECT P9 (EAT Standard Score - 81)

Simplifying phonological processes:	**Examples:**
Stopping of fricatives (in word initial position)	Van -> [ban] Zip -> [dɪp] Fish -> [bɪd] Sun -> [dʌn] Thumb -> [bʌm]
Stopping of affricates (in word initial position)	Chair -> [deə] Jam -> [dam]
Voicing of word initial voiceless stops	Tap -> [dap] Pen -> [bɛn] Car -> [gaʳ]
Reduction of word initial /s/+consonant clusters	Smoke -> [mok] Snow -> [no] Sky -> [gae] Spoon -> [bun]
Glide/liquid simplifications	Leaf -> [wif] Red -> [wɛd] Yoyo -> [lolo]

SUBJECT P10 (EAT Standard Score - 79)

Simplifying phonological processes:	**Examples:**
Glottal replacement of word final consosnant	Black -> [bwaʔ] That -> [aʔ] Sock -> [sɔʔ] Knife -> [nʌiʔ]
Fronting of velars	Car -> [taˑ] Bag -> [bad] Wing -> [wɪn]
Stopping of affricates (in word initial position)	Chair -> [dɛʌ] Jam -> [dam]
Voicing of word initial voiceless stops	Pen -> [bɛn] Toe -> [do]
Reduction of word final consonant clusters	Help -> [hɛp] Cold -> [dɔːd]

SUBJECT P11 (EAT Standard Score - 64)

Simplifying phonological processes:	**Examples:**
Deletion of word final consonants and consonant clusters	Ball -> [bɔ] Watch -> [wɔ] Leaf -> [li] Sun -> [sʌ] Salt -> [sɔ]
Stopping of affricates (in word initial position)	Chair -> [tiʌ] Jam -> [dam] Chips -> [tɪp]

(SUBJECT P11 - continued)

Reduction of word initial consonant clusters	Crown -> [kʌu]
	Grass -> [ga]
	Smoke -> [mo]
	Spoon -> [bʉ]

SUBJECT P12 (EAT Standard Score - 53)

Simplifying phonological processes:	**Examples:**
Glottal replacement of word final and medial consonants and clusters	Monkey -> [nʌʔi]
	Christmas -> [kɪʔʌ]
	Smoke -> [m̥ᶠmoʔ]
	Thumb -> [fʌʔ]
Deletion of word final consonants & clusters (with prolongation of vowel)	Train -> [te:]
Reduplication	Umbrella -> [əwəʋɛwə]
Reduction of consonant clusters	Smoke -> [m̥ᶠmoʔ]
	Queen -> [ki:]
	Spoon -> [pʰʉʔ]
	Tent -> [tɛt]
Glide/liquid simplifications	Glove -> [gjʌʔ]
	Bridge -> [bwɪʔ]
	Elephant -> [ɛɹiʔə]
Fronting of alveolar & palato-alveolar fricatives (in word initial position)	Soldier -> [θoʔʌ]
	Scissors -> [θɪʔʌ]
	Shed -> [θɛd]
Fronting of interdental fricatives (in word initial position)	Thumb -> [fʌʔ]
	Three -> [fi]

APPENDIX 2

ILLUSTRATIONS OF THE 'LANGUAGE MASTER' CARDS

USED IN THE DATA COLLECTION PROCEDURE

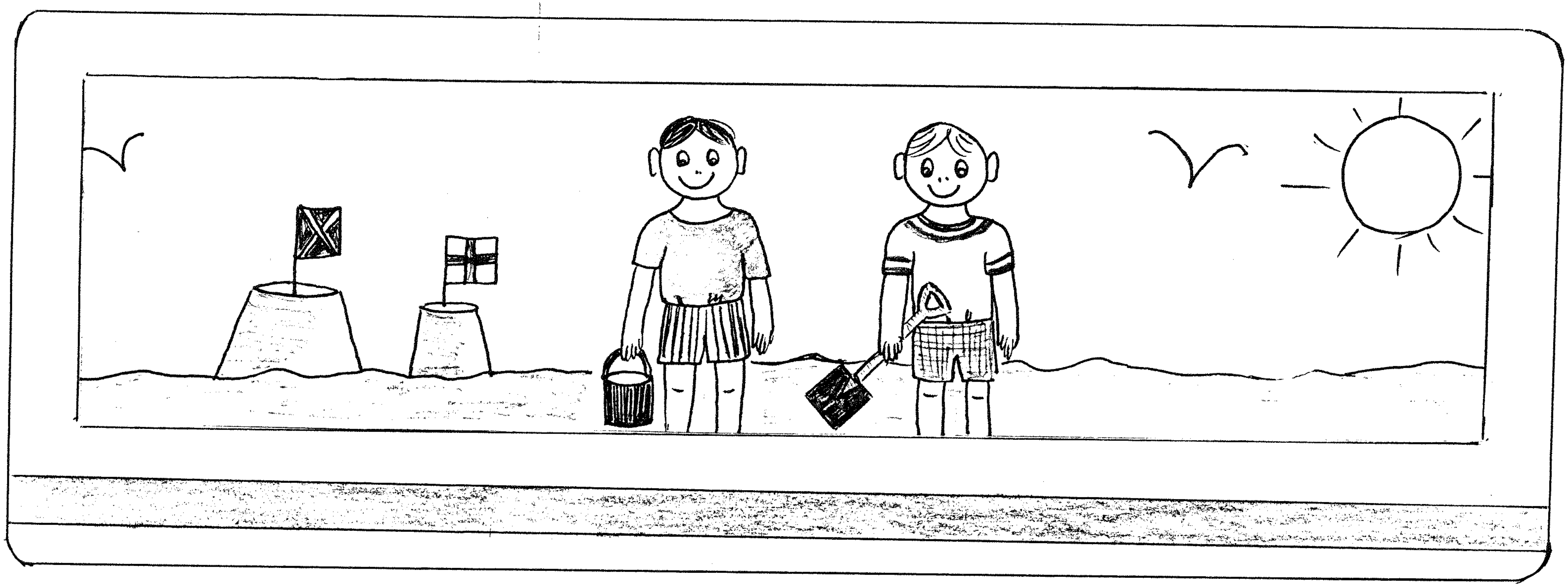

Illustration of Language Master cards 1, 4 & 7 used in the data collection procedure. The magnetic strip below the picture (represented here by a shaded strip) carried an audio recording of the utterance, '<u>Two wee boys are playing in the sand</u>'.

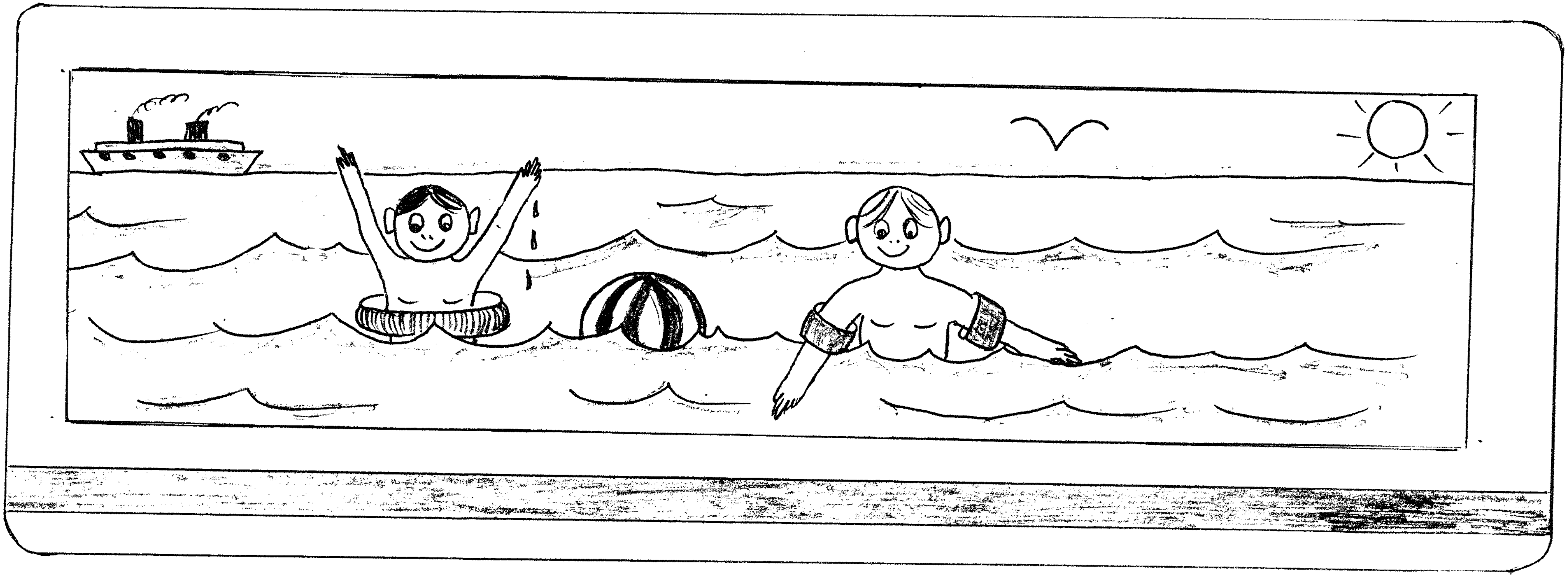

Illustration of Language Master cards 2, 5 & 7 used in the data collection procedure. The magnetic strip below the picture (represented here by a shaded strip) carried an audio recording of the utterance '<u>Two wee boys are playing in the sea</u>'.

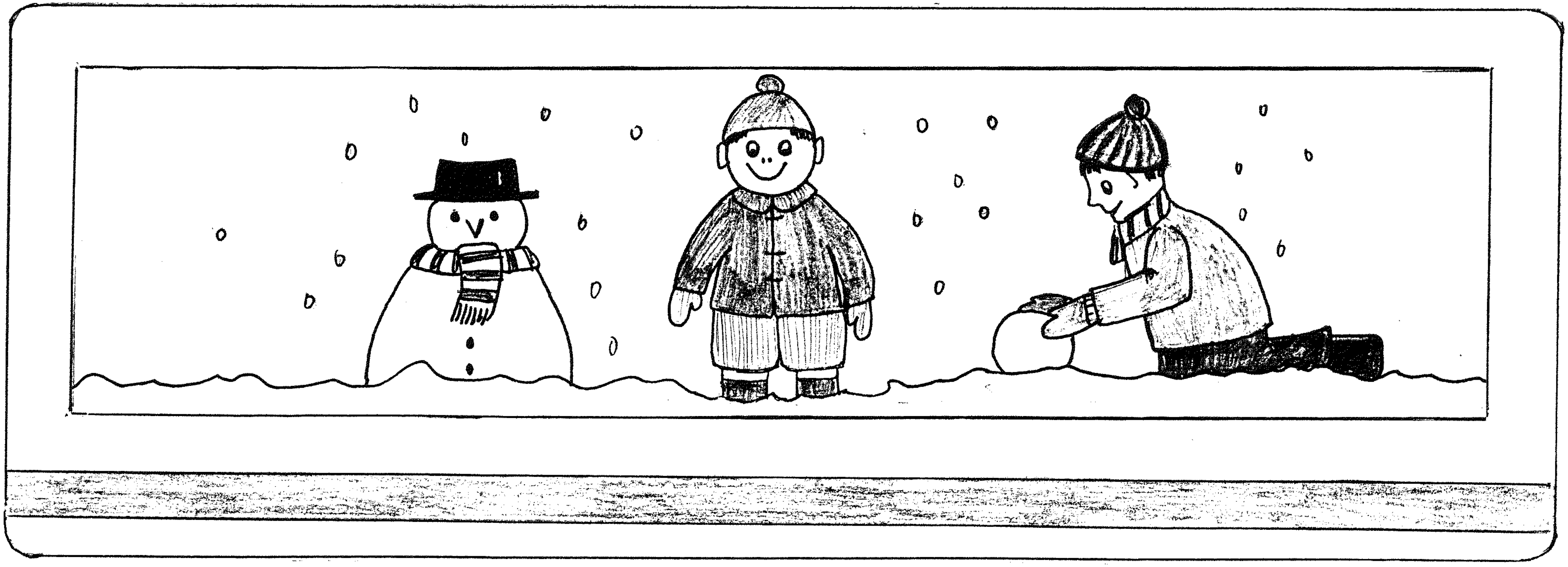

Illustration of Language Master cards 3, 6 & 9 used in the data collection procedure. The magnetic strip below the picture (represented here by a shaded strip) carried an audio recording of the utterance '<u>Two wee boys are playing in the snow</u>'.

APPENDIX 3A

ANALYSIS SHEETS SHOWING THE PHONOLOGICAL FORM OF

EACH TOKEN OF THE EXPERIMENTAL PHRASE

SPOKEN BY N-GROUP SUBJECTS

(in comparison with the usual form found in the adult data)

(The final two sheets of this appendix summarize each N Group subject's realisations of the segments included in the temporal acoustic analysis.)

ANALYSIS OF PHONOLOGICAL FORM SUBJECT: N1

Mean phrase duration (seconds): 1.72

Rank within group for mean phrase duration: 9

*REALISATION OF EACH SEGMENT IN EACH TOKEN

Token Number

Usual adult forms	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
/tʰ																		
tɹ				t͡ɹə														
w																∅		
i																		
b											bʰ	b̥			pʰ			
ɔe													ɔ͡ɔɪ				ə͡i	
z	z̥		∅	z̥	z̥				z̥	z̥			z̥	ʃ̟	ẓ̊			z̥
ʌ̂ʳ	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅		∅	∅	∅	∅	∅
pʰ					f			b					f					
l																		
e																		
ɪ	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅		∅	∅	∅		∅	∅
ŋ	n	n	n	n	n	n	n	n	n	n	nᵈ	n	n	n	n	n	n	n
ɪ							ɪ̃						∅					
n													n̩					
ɣ	∅	d	d		∅	∅	d̆	∅		∅	d		dð	d	d	∅	d	∅
ə/																		
Phrase duration (S)	1.5	1.4	1.8	1.8	1.7	1.8	1.8	1.7	1.7	1.7	1.9	1.7	1.9	1.6	1.7	1.9	1.5	1.8
Number of segments	14	15	14	15	14	14	15	14	15	14	15	16	15	15	15	14	14	14
Number of syllables	6	6	6	6	6	6	6	6	6	6	6	7	7	6	6	7	6	6

* A blank space indicates that the segment was adult-like.

ANALYSIS OF PHONOLOGICAL FORM   SUBJECT: N2

Mean phrase duration (seconds): 1·77

Rank within group for mean phrase duration: 11

*REALISATION OF EACH SEGMENT IN EACH TOKEN

Token Number

Usual adult forms	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
/tʰ																		
ʉ																		
w																	token 17 excluded — noise on recording	
i																		
b																		
ɔe			ɔ͡ɪə										ɔ̞i					
z			z̥													ʒ̊		z̊
ʌʳ	Ø	Ø	Ø															
pʰ																		
l																		
e																		
ɪ																		
ŋ																		
ɪ																		
n																		
ð	Ø	Ø		Ø	Ø	Ø				Ø	Ø	Ø	Ø	Ø	Ø	Ø		Ø
ə/																		
Phrase duration (s)	1·7	1·4	1·9	1·7	1·7	1·8	2·1	1·9	1·8	1·7	2·1	1·8	1·7	1·8	1·7	1·8		1·5
Number of segments	15	15	16	16	16	16	17	17	17	16	16	16	16	16	16	16		16
Number of syllables	7	7	7	8	8	8	8	8	8	8	8	8	8	8	8	8		8

* A blank space indicates that the segment was adult-like.

ANALYSIS OF PHONOLOGICAL FORM **SUBJECT:** N3

Mean phrase duration (seconds): 1·69

Rank within group for mean phrase duration: 8

*REALISATION OF EACH SEGMENT IN EACH TOKEN

Token Number

Usual adult forms	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
/tʰ																		
ʉ			i															
w																		
i																		
ð	ð̥																	
ɔe				ɔ͡:i										ɔ͡:i				
z													ž					
ʌ͡r		ə̆															ə̆	
pʰ																		
l																		
e																		
ɪ		∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
ŋ		n		n		ŋ̊	n	n	n		n	n			n			n
ɪ																		
n								∅										
ɣ		∅					∅	∅		∅	∅	∅	∅					
ə/																		
Phrase duration (s)	1·6	1·3	H[*]	+	1·7	1·9	1·6	1·6	1·7	2·0	1·8	1·8	1·7	1·9	1·8	1·7	1·5	1·6
Number of segments	17	15	16	16	16	16	15	14	16	15	15	15	15	16	16	16	16	16
Number of syllables	8	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7

*** A blank space indicates that the segment was adult-like.**

(*) H = hesitation

+ Release of initial segment obscured by noise.

ANALYSIS OF PHONOLOGICAL FORM **SUBJECT:** N4

Mean phrase duration (seconds): 1·43

Rank within group for mean phrase duration: 3

*REALISATION OF EACH SEGMENT IN EACH TOKEN

Token Number

Usual adult forms	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
/tʰ																		
ɬ																		
w																		
i																		
b							b͡ɸ				b͡ɸ			b͡ʋ				
ɔe																		
z		ç		z̳		z̥		ž	j									
ʌ̂r						ɪz												
pʰ																		
l																		
e								e̟			e̟						e̟	
ɪ	∅		∅	∅		∅		∅	∅								∅	∅
ŋ	n					n			n									
ɪ																		
n																		
ɣ	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
ə/																		
Phrase duration (s)	1·2	1·3	1·8	1·3	1·5	1·4	1·6	1·4	1·7	1·3	1·4	1·4	1·3	1·4	1·5	1·5	1·4	1·4
Number of segments	15	16	15	15	16	16	16	15	15	16	16	16	16	16	16	16	15	15
Number of syllables	7	8	7	7	8	7	8	7	7	8	8	8	8	8	8	8	7	7

*** A blank space indicates that the segment was adult-like.**

ANALYSIS OF PHONOLOGICAL FORM **SUBJECT:** N5

Mean phrase duration (seconds): 1.72

Rank within group for mean phrase duration: 10

*REALISATION OF EACH SEGMENT IN EACH TOKEN

Token Number

Usual adult forms	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
/tʰ	d	t⁼	t⁼		t⁼		d		d	t⁼		d	t⁼	t⁼		t⁼	t⁼	
ɑ																		
w																		
i																		
b			b	b̚				b̚							b̚		b̚	
ɔe																		
z	z̥	z̥	s		s	d͡z	z̥	s	z̥	z̥		z̥	z̥	z̥	z̥		z̥	
ʌɾ																		
pʰ	p													p̚				
l																		
e																		
ɪ	∅	∅	∅					∅	∅	∅	∅			∅	∅	∅		
ŋ	n	n	n		n	n	n	n	n	n	n	n	n	n	n	n	n	n
ɪ																		
n																		
ɣ	d	d	d	dɣ	d		d	d	d	d	dɣ	d	d	dɣ	d	dɣ	d	d
ə/																		
Phrase duration (S)	1.7	H*	1.9	1.8	H*	1.8	1.9	1.8	1.8	1.8	1.7	1.5	1.7	1.6	1.5	1.6	1.9	1.6
Number of segments	16	16	16	17	17	17	17	16	16	16	16	17	17	16	16	16	17	17
Number of syllables	7	7	7	8	8	8	8	7	7	7	7	8	8	7	7	7	8	8

*** A blank space indicates that the segment was adult-like.**

*H = Hesitation

ANALYSIS OF PHONOLOGICAL FORM **SUBJECT:** N6

Mean phrase duration (seconds): 1·53

Rank within group for mean phrase duration: 6

*REALISATION OF EACH SEGMENT IN EACH TOKEN

Token Number

Usual adult forms	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
/tʰ	t=		t=		t=				t=									
t̴																		
w																		
i									ɪ	ɪ	ɪ	ɪ	ɪ	ɪ		ɪ		
b		b																
æ																	ɔ͡:ɪ	
z		d	d															
ʌ̃		∅			əz													
pʰ		f:					f											
l	∅	∅																
e													ẹ					
ɪ	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
ŋ	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	∅	n
ɪ																		
n																	n:	n:
ð	∅	∅	∅	∅	∅			∅	∅		∅	∅	∅	∅	∅	∅	∅	∅
ə/															∅			∅
Phrase duration (S)	1·3	1·4	1·3	1·3	H*	1·9	1·7	1·6	1·6	1·5	1·6	1·6	1·4	H*	1·5	1·5	1·9	1·5
Number of segments	14	13	15	15	16	16	16	15	15	16	15	15	15	15	14	15	14	14
Number of syllables	7	7	7	7	7	7	7	7	7	7	7	7	7	7	6	7	7	6

*** A blank space indicates that the segment was adult-like.**

*H = Hesitation

ANALYSIS OF PHONOLOGICAL FORM **SUBJECT:** N7

Mean phrase duration (seconds): 1·67

Rank within group for mean phrase duration: 7

*REALISATION OF EACH SEGMENT IN EACH TOKEN

Token Number

Usual adult forms	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
/tʰ																		
tt																		
w	∅	∅	∅															
i	∅	∅	∅															
b																		
ɔe																		
z	z̥		z̠			ç̬	ç̬				z̥							
ʌv	∅		∅	∅	∅	∅	∅	∅	∅	∅	∅							
pʰ																		
l																		
e																		
ɪ														∅			∅
ŋ	n																	
ɪ																		
n																		
ɣ																		
ə/																		
Phrase duration (S)	1·3	1·5	1·4	1·7	1·8	1·6	1·6	1·6	1·8	1·7	1·6	1·8	1·8	1·8	1·7	1·6	2·0	1·8
Number of segments	14	15	14	16	16	16	16	16	16	16	16	17	17	17	16	17	17	16
Number of syllables	6	7	6	7	7	7	7	7	7	7	7	8	8	8	7	8	8	7

*** A blank space indicates that the segment was adult-like.**

ANALYSIS OF PHONOLOGICAL FORM **SUBJECT:** N8

Mean phrase duration (seconds): 1.53

Rank within group for mean phrase duration: 5

*REALISATION OF EACH SEGMENT IN EACH TOKEN

Token Number

Usual adult forms	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
/t								t⁼			d							
aɪ				ə		y̝	ụ				ə							
w	v		† ←															→
i			←															→
b	v	v		b	b		b̥					pʰ			w	β̱	pʰ	
ɔe																		
z		ž	z̊		ʃ͡v		z̠	z̠			ž̠							z͡ʋ
ʌ͡r												ɪz						
pʰ	f	f																
l											∅							
e				ẹ	ẹ				e:		e:	ẹ			e			
ɪ	∅	∅	∅	∅	∅		∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
ŋ	n	n	n				ŋ:	∅	∅	∅	∅	ŋ:					∅	∅
ɪ				∅			∅			∅		∅						
n	∅	∅		∅														
ɣ	∅	∅			∅		∅	∅				∅					∅	∅
ə/	∅																	
Phrase duration (S)	1.4	1.5	H⊕	1.5	1.8	1.7	1.6	1.5	1.5	1.5	1.4	1.8	1.5	1.5	1.5	1.4	1.5	1.5
Number of segments	13	14	18	16	17	19	16	16	17	16	16	17	18	18	18	18	16	16
Number of syllables	6	7	8	7	8	8	8	8	8	7	8	7	8	8	8	8	8	8

*** A blank space indicates that the segment was adult-like.**

† In tokens 3-18 the word 'little' [lɪtə] is substituted for the word 'wee'.

⊕ = Hesitation

ANALYSIS OF PHONOLOGICAL FORM SUBJECT: N9

Mean phrase duration (seconds): 1·11

Rank within group for mean phrase duration: 1

*REALISATION OF EACH SEGMENT IN EACH TOKEN

Token Number

Usual adult forms	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
/tʰ															d̥			Token 18 Excluded — noise on recording
t												t̆						
w					w̃l	ʋ			b			w̆	w̆				ŵ	
i												ə̆						
b	v					v	b̥	v			v	bv	ʋ				b	
ɹe																	ɹ̆i	
z						z̥				ž		ž		∅	ź	ž	∅	
ʌ̂r						∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	
pʰ	f			f		f			b									
l																		
e											ẽ	ĕ		ĕ	ẽ	ẽ	ẽ	
ɪ		∅					∅		∅		∅	∅	∅	∅	∅	∅	∅	
ŋ		∅					∅	ŋ̆		ŋ̆	∅	∅		∅	∅	∅	∅	
ɪ									ɪ̆		ɪ̃	ɪ̆	ɪ̆	∅	ɪ̃	ɪ̃	ɪ̃	
n									n̆	∅	∅	∅	∅		∅	∅	∅	
ð		∅					∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	
ə/									ə̆	∅	∅	∅	∅		ə̃	∅	∅	
Phrase duration (S)	1·5	1·3	1·4	1·5	1·4	1·3	1·1	1·1	1·3	1·0	0·9	0·8	0·9	0·9	1·0	0·8	0·8	
Number of segments	17	14	17	17	17	16	13	15	14	13	11	11	12	11	12	11	10	
Number of syllables	8	7	8	8	8	7	6	7	6	6	6	5	5	5	6	5	5	

* A blank space indicates that the segment was adult-like.

ANALYSIS OF PHONOLOGICAL FORM **SUBJECT:** N10

Mean phrase duration (seconds): 1·23

Rank within group for mean phrase duration: 2

*REALISATION OF EACH SEGMENT IN EACH TOKEN

Token Number

Usual adult forms	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
/tʰ																		
ʉ						u:	ə	ə			ə		u:	ʉ̥	u:			ə̥
w	∅					†			†		b	†	†	†	†	∅	†	†
i	∅															∅		
b			b̚		(bᵛ̚)													
ɔe		ɔ				ɔ				ɔ͡ɪ̆							ɔ͡ɪ̯	ɔ͡ɪ̯
z	ž̥	ž̥	∅	z̥		∅		∅		∅	ž̥	∅	∅	ž̥	(ž̥)	∅	∅	∅
͡ɹ	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
pʰ			f̂ʷ					ɸ	p̂ᶲ		b							
l	w	∅	∅		w	∅		∅	∅		∅				w	∅	∅	
e						ɪ											ə	
ɪ	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
ŋ	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
ɪ	ə	∅	ə̆	∅	∅	∅	∅	∅	∅	∅			∅			ə	∅	
n							n:		n:									
ð		∅	∅	∅	∅	∅	∅	∅	∅	∅	∅		∅	∅	∅	∅	∅	∅
ə/		ə̆		∅			∅	∅			∅		∅	∅			ə̆	
Phrase duration (s)	1·0	1·2	1·3	H⊕	1·3	1·6	1·4	0·9	1·4	1·1	1·2	1·3	H	1·2	1·4	0·9	1·2	1·2
Number of segments	12	11	11	12	12	12	11	9	13	11	11	15	12	14	15	9	12	14
Number of syllables	5	5	6	4	5	6	4	4	6	5	5	7	6	6	7	5	6	7

*** A blank space indicates that the segment was adult-like.**

† in these tokens the word 'wee' was realised as 'little' – various forms :- [lɪtl̩] ; [wɪtəl] ; [wɪʃʊ] ; [wɪθə].

⊕H = Hesitation

ANALYSIS OF PHONOLOGICAL FORM **SUBJECT:** N11

Mean phrase duration (seconds): 1·8

Rank within group for mean phrase duration: 12

*REALISATION OF EACH SEGMENT IN EACH TOKEN

Token Number

Usual adult forms	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
/tʰ																		
ɪə											u:							
w																		
i																		
b																		
ɔe						ɔ̂i:												
z	s	ø	ž	s	z̥		s̱					s	j			s̱	s̱	z̥
ʌ͡r	ø	ø	ø	ø	ø	ø	ø	ø	ø									
pʰ						p^{Φ}:												
l																		
e								e:										
ɪ	ø	ø	ø		ø		ø	ə	ø	ø	ø	ø	ø	ø		ø	ø	ø
ŋ	n	n	n	n	n	n	n	ø	n	n	n	n	n	n	n	n	n	n
ɪ					ʌ							ɪ̃			ʌ̃		ʌ	
n									n:									
ð																		
ə/																		
Phrase duration (S)	1·5	H⊛	H	1·8	1·6	H	1·6	1·7	1·8	2·0	H	2·1	1·9	1·8	2·0	1·9	1·8	1·9
Number of segments	15	14	15	16	15	16	15	15	15	16	16	16	16	16	17	16	16	16
Number of syllables	6	6	6	7	6	7	6	7	6	7	7	7	7	7	8	7	7	7

*** A blank space indicates that the segment was adult-like.**

⊛ H = Hesitation

ANALYSIS OF PHONOLOGICAL FORM SUBJECT: N12

Mean phrase duration (seconds): 1.45

Rank within group for mean phrase duration: 4

*REALISATION OF EACH SEGMENT IN EACH TOKEN

Token Number

Usual adult forms	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
/tʰ													∅			t͡s		
ʊ													∅			u:		
w							∅											
i																		
b	b̥	w		w			bʷ			b̥		b̥						
æ										ɪ͡ə								
z										∅	∅		z̆				z̆	
ʌr	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
pʰ		f										f						
l	w	∅			∅							∅						w
e								e:					e:					
ɪ	∅	∅			∅		∅		∅	∅	∅	∅		∅	∅	∅		
ŋ	∅	∅	n	n	n	n	n	j	n	n	n	n	n	n	∅	∅	n	
ɪ																		
n				∅			∅					∅						
ð	∅	∅		∅	∅						∅	∅		∅				
ə/																		
Phrase duration (S)	1.2	1.2	1.7	1.3	1.5	1.4	1.6	H⊛	1.4	1.4	1.5	1.2	1.4	1.4	1.4	2.0	1.5	1.8
Number of segments	13	12	16	14	13	16	13	16	15	14	13	12	14	14	14	14	16	16
Number of syllables	6	6	7	7	6	7	6	7	6	6	6	6	7	6	6	6	7	7

*** A blank space indicates that the segment was adult-like.**

⊛ H = Hesitation

SUMMARY OF 'N' SUBJECTS' REALISATIONS OF THE SEGMENTS INVOLVED IN THE TEMPORAL ACOUSTIC ANALYSIS.

Subj.	/t/ in 'two'	/b/ in 'boys'	vowel in 'boys'	/pl/ in 'playing'
N1	18* [tʰ]	15 [b] 1 [pʰ] 1 [bʰ] 1 [b̚]	16 [ɔe] 1 [ɔ͡ɔɪ] 1 [ə͡i]	15 [pʰl] 2 [fl] 1 [bl]
N2	17 [tʰ]	17 [b]	15 [ɔe] 1 [ɔ͡iᵊ] 1 [ɔ̟i]	17 [pʰl]
N3	18 [tʰ]	17 [b] 1 [b̚]	16 [ɔe] 2 [ɔːi]	18 [pʰl]
N4	18 [tʰ]	15 [b] 2 [b͡ɸ] 1 [b͡v]	18 [ɔe]	18 [pʰl]
N5	6 [tʰ] 8 [t⁼] 4 [d]	13 [b] 5 [b̚]	18 [ɔe]	16 [pʰl] 1 [p̚ᶲl] 1 [p̚l]
N6	14 [tʰ] 4 [t⁼]	17 [b] 1 [b̚]	17 [ɔe] 1 [ɔːɪ]	15 [pʰl] 1 [pʰ] 1 [fː] 1 [fl]

* Number of occurrences of each realisation.

SUMMARY OF 'N' SUBJECTS' REALISATIONS OF THE SEGMENTS INVOLVED IN THE TEMPORAL ACOUSTIC ANALYSIS. (continued)

Subj.	/t/ in 'two'	/b/ in 'boys'	vowel in 'boys'	/pl/ in 'playing'
N7	18* [tʰ]	18 [b]	18 [ɔe]	18 [pʰl]
N8	16 [tʰ] 1 [t⁼] 1 [d]	9 [b]; 2 [b] 1 [b̥]; 2 [pʰ] 1 [w]; 2 [v] 1 [β]	18 [ɔe]	15 [pʰl] 1 [pʰ] 2 [fl]
N9	16 [tʰ] 1 [d̥]	9 [b]; 1 [b] 1 [b̥]; 1 [b͡v] 4 [v]; 1 [ʋ]	16 [ɔe] 1 [ɔ̃ĭ]	13 [pʰl] 1 [bl] 3 [fl]
N10	18 [tʰ]	16 [b] 1 [b̥] 1 [b̥ʋ]	13 [ɔe] 3 [ɔĭ] 2 [ɔ]	7 [pʰl] 4 [pʰ]; 1 [pᶲ] 3 [pʰw], 1 [bl] 1 [f͡w̃]; 1 [ɬ]
N11	18 [tʰ]	18 [b]	17 [ɔe] 1 [ɔ̃iː]	17 [pʰl] 1 [pᶲːl]
N12	16 [tʰ] 1 [t͡s]	12 [b] 3 [b̥] 2 [w] 1 [bʷ]	17 [ɔe] 1 [ɔ̃ɪᵊ]	13 [pʰl] 1 [pʰ] 2 [pʰw] 2 [f]

* Number of occurrences of each realisation.

APPENDIX 3B

ANALYSIS SHEETS SHOWING THE PHONOLOGICAL FORM OF

EACH TOKEN OF THE EXPERIMENTAL PHRASE

SPOKEN BY P-GROUP SUBJECTS

(in comparison with the usual form found in the adult data)

(The final two sheets of this appendix summarize each P Group subject's realisations of the segments included in the temporal acoustic analysis.)

ANALYSIS OF PHONOLOGICAL FORM **SUBJECT:** P1

Mean phrase duration (seconds): 1-68

Rank within group for mean phrase duration: 7

*REALISATION OF EACH SEGMENT IN EACH TOKEN

Token Number

Usual adult forms	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
/tʰ																		
ʉ			u	ə			u		u	u				* ʉ/ʉ				
w																		
i																		
b																		
æ		ɔ			ɔ	ɔɪ̆	ɔɪ̆	ɔɪ̆		ɔɪ̆	ɔɪ̆	ɔɪ̆					ɔɪ̆	ɔɪ̆
z	Ø	z̥̆	Ø	z͇̊	z̥̆	z̥̆	d̥	z̥̆	z͇̊	z͇̊	z̥	d͡z	z͇	d͡z	Ø	z̥	d	Ø
ʌ̃ɹ	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
pʰ	p˭	b	p˭	b	b	b̰	b	b	b	b	b	p˭	p˭	b	p˭		b	b
l	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
e		e̜			ẽ						ẽ̤	ɛ						
ɪ	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
ŋ	n	n	n	n	n	n	n	n	n	n	n	d̚	Ø	Ø	d	Ø	n	n
ɪ	ɪ̃				ɪ̃	ɪ̃	ɪ̃	ʌ̃		ɪ̃	ɪ̃	Ø		ʌ				
n	Ø			Ø						Ø	Ø							
ɣ	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
ə/	ə̃			Ø	ə̃	ə̃				Ø	Ø			ʌ				
Phrase duration (S)	1·7	1·7	1·7	1·4	1·7	1·7	1·7	1·6	1·6	1·5	1·5	1·8	1·9	1·9	1·7	2·0	1·7	1·7
Number of segments	11	13	12	11	13	13	13	13	13	11	11	12	12	12	12	12	13	12
Number of syllables	6	6	6	5	6	6	6	6	6	5	5	5	6	6	6	6	6	6

*** A blank space indicates that the segment was adult-like.**

* [ʉ/ʉ] - indicates a discontinuity was perceived within the segment.

ANALYSIS OF PHONOLOGICAL FORM **SUBJECT:** P2

Mean phrase duration (seconds): 1·73

Rank within group for mean phrase duration: 9

*REALISATION OF EACH SEGMENT IN EACH TOKEN

Token Number

Usual adult forms	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
/tʰ													d		d			d
~~tt~~																		
w																		
i																		
b																		
ɔe			ɔɪ̆	ɔɪ̆	ɔi											ɔː		
z	v	v	d͡z	d	d	d	d	d	d	d	d		d		d	d	z̥̆	d
ʌ̃r																ə̆	∅	
pʰ	b	b		f	F								p̃ᶠ	p̱			F	
l		∅		∅	∅								∅				∅	
e					ẽ				e̤									
ɪ	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
ŋ	n	n	n	n	n	n	n	nː	n	n	n	n	n	n	n	n	n	n
ɪ								∅										ə
n								∅										
ɣ	∅		∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
ə/					∅	∅			∅		∅			∅				∅
Phrase duration (S)	1·7	1·7	2·0	1·8	1·7	1·8	1·6	1·9	1·8	1·9	1·7	1·7	1·8	1·6	1·5	1·7	1·7	1·6
Number of segments	15	15	15	14	13	14	15	13	14	15	14	15	14	14	15	15	13	14
Number of syllables	7	7	7	7	6	6	7	6	6	7	6	7	7	6	7	7	6	6

* A blank space indicates that the segment was adult-like.

ANALYSIS OF PHONOLOGICAL FORM **SUBJECT:** P3

Mean phrase duration (seconds): 1·42

Rank within group for mean phrase duration: 4

*REALISATION OF EACH SEGMENT IN EACH TOKEN

Token Number

Usual adult forms	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
/tʰ	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
ʧ	ʔʧ	ʔʧ	ʔʧ	ʔʧə	ʔʧə	ʔʧə	ʔʧə	ʔʧə	ʔʧ	ʔʧə	ʔʧə	ʔʧə	ʔʧə	ʔʧə	ʔʧə	ʔʧə	ʔʧə	ʔʧə
w	∅	∅	∅	∅	∅	∅	∅	∅	w̆	∅	∅	∅	∅	∅	∅	∅	∅	∅
i	∅	∅	∅	∅	∅	∅	∅	∅	ə	∅	∅	∅	∅	∅	∅	∅	∅	∅
b																		
ɔe								ʒ		ɔɪ̆	ɔɪ̆							
z	∅	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	∅	✓
ʌ̃r																		
pʰ	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b
l	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
e																		
ɪ	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
ŋ	n	n		n	n		n	n	n	n	n	n	n	n	n	n	n	n
ɪ																		
n																		
ɣ	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
ə/																		
Phrase duration (S)	1·4	1·4	1·4	1·4	H*	1·4	1·4	1·5	1·5	1·2	H	1·5	H	1·4	1·3	1·5	H	1·6
Number of segments	10	11	11	11	11	11	11	11	13	11	11	11	11	11	11	11	10	11
Number of syllables	6	6	6	6	6	6	6	6	7	6	6	6	6	6	6	6	6	6

*** A blank space indicates that the segment was adult-like.**

* H = Hesitation

ANALYSIS OF PHONOLOGICAL FORM **SUBJECT:** P4

Mean phrase duration (seconds): 1·6

Rank within group for mean phrase duration: 6

*REALISATION OF EACH SEGMENT IN EACH TOKEN

Token Number

Usual adult forms	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
/tʰ	d	d	d	d	d	d	d		d	d	d	d	d	d	d	∅	d	
tt							ə									ʔt		
w	d	†	d	†	†		∅	d	†	†	†	†	†	†	†		†	†
i	ɪ		ə				ɪ	ɪ										
b																		
ɔe																	ʔɔɔːɪ	
z																	z̥	
ʌr	∅	∅	∅	∅	∅		∅	∅	∅	∅	∅	∅	∅	∅	∅			∅
pʰ	b	b	b	b	b	b	b	b	b	p⁼	b	b	p⁼	b	b	b	b	b
l	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
e																		
ɪ	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
ŋ	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
ɪ													ɪ̃					
n												∅		∅		∅	∅	
ɣ	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
ə/																		
Phrase duration (S)	1·5	1·5	H*	1·8	1·6	1·5	1·8	1·6	H	1·6	1·6	1·4	1·7	1·7	1·5	1·3	2·1	1·5
Number of segments	12	14	13	15	14	12	12	13	14	14	14	13	14	13	14	11	13	15
Number of syllables	6	7	6	7	7	6	6	6	7	7	7	7	7	7	7	7	8	8

* H = Hesitation

*** A blank space indicates that the segment was adult-like.**

† in these tokens the word 'little' was substituted for 'wee' – various realisations:– [ɪdə]; [ɪt⁼ə]; [dɪdə]; [ɪʔə]

ANALYSIS OF PHONOLOGICAL FORM SUBJECT: P5

Mean phrase duration (seconds): 2·31

Rank within group for mean phrase duration: 12

*REALISATION OF EACH SEGMENT IN EACH TOKEN

Token Number

Usual adult forms	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
/tʰ																		
tt		tt:		tt:			⊛tt/tt	tt/tt			tt:	tt/tt			tt/tt			tt/tt
w																		
i																		
b																		
ɔe																		
z	d	d	d	d	d		d	d	d	d	d	d	d	d	d	d	d	d
ʌ̃ɹ																		
pʰ																		
l	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
e																		
ɪ				ə	ə̆	ə̆	ə̆						ə̆	ə̆				
ŋ	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
ɪ																		
n																		
ɣ	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
ə/																		
Phrase duration (S)	2·6	2·5	2·3	2·6	2·2	2·2	2·2	2·3	2·3	2·2	2·3	2·4	2·1	2·3	2·2	2·2	2·2	2·5
Number of segments	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Number of syllables	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8

⊛ Indicates a discontinuity was perceived within segment

*** A blank space indicates that the segment was adult-like.**

ANALYSIS OF PHONOLOGICAL FORM SUBJECT: P6

Mean phrase duration (seconds): 1·86

Rank within group for mean phrase duration: 11

*REALISATION OF EACH SEGMENT IN EACH TOKEN

Token Number

Usual adult forms	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
/tʰ																		
ɨ							ə											
w	wl	Ø	Ø		Ø		Ø		Ø			Ø	Ø			Ø	Ø	
i			I	Î^ə			I								I		Î^ə	
b			b̥															
ɔe																		
z																		ž
ʌ̂^{r}																		
pʰ										p	b							
l	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
e																		
I	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
ŋ	Ø	n	n		Ø	Ø		Ø					Ø		Ø	Ø	Ø	Ø
I					ʌ̃	ʌ̃	ʌ̃		ʌ̃	ʌ̃	ʌ̃	ʌ̃		ʌ̃	ʌ̃	ʌ̃	ʌ̃	ʌ̃
n																	Ø	Ø
ɣ	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d
ə/																		
Phrase duration (s)	1·8	1·9	1·8	1·8	1·8	1·6	1·9	1·9	1·9	2·1	1·9	1·9	2·0	1·9	1·8	1·9	1·9	1·7
Number of segments	14	14	14	15	12	13	13	14	14	15	15	14	13	15	14	13	12	13
Number of syllables	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7

*** A blank space indicates that the segment was adult-like.**

ANALYSIS OF PHONOLOGICAL FORM SUBJECT: P7

Mean phrase duration (seconds): 1·08

Rank within group for mean phrase duration: 2

*REALISATION OF EACH SEGMENT IN EACH TOKEN

Token Number

Usual adult forms	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
/tʰ					tʰ:												d	
ʉ						ʉ/ʉ†			ũi				ũi					
w	∅	∅	∅		∅			∅	∅		∅	∅	∅	∅	∅	∅	∅	∅
i									∅				∅	Iᵊ				
b	ʋ̃˺							bᶹ					ʋ	ʋ	ʋ̥	ʋ	ʋ	w
æ	ɔ								ɔ				ɔ	ɔ̃ᵊ	ɔ	ɔɪ̆	ɔ	ɔ
z	∅	ž̠	z̥		z̠		ž̠	∅	d	∅	∅	∅	∅	∅	∅	ž̠	d	∅
ʌʳ	∅	ə̆		∅		∅	ə̆	∅	ə̆			∅	∅	∅	∅	∅	∅	∅
pʰ	β˺f			f		β˺ᶲ	β˺	b˺ᶲ					v	β̄f	v	v̥	v	v
l	∅	∅	∅	∅	∅	∅	∅	∅		∅	∅	∅	∅	∅	∅	∅	∅	∅
e													e:					
I	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
ŋ	n	n	n	n	n	n	n	n	n	n	n	n	∅	n	n	n	n	n
ɪ		∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
n	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
ð	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
ə/	∅																	
Phrase duration (S)	1·0	H⊛	1·3	1·2	1·3	1·2	1·2	0·9	1·1	1·2	1·2	1·0	0·9	1·1	1·0	0·9	0·9	0·9
Number of segments	9	11	11	11	11	11	12	9	11	11	10	9	7	9	8	9	9	8
Number of syllables	5	6	6	5	6	5	6	5	5	6	6	5	4	5	4	4	4	4

⊛ H = Hesitation

*** A blank space indicates that the segment was adult-like.**

†[ʉ/ʉ] indicates a discontinuity was perceived within segment.

ANALYSIS OF PHONOLOGICAL FORM   SUBJECT: P8

Mean phrase duration (seconds): 1·05

Rank within group for mean phrase duration: 1

*REALISATION OF EACH SEGMENT IN EACH TOKEN

Token Number

Usual adult forms	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
/tʰ									d					d				t⁼
ʉ										ʊᵊ								
w	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
i	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
b					w		β b̚											
ɔe																		
z	z̥	z̥	z̥		z̥̆					z̥		Ø						
ʌ̃r	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
pʰ	p⁼	b	pᶲ		b	b	p̚ᶲ	b	b	b	b			b	b			
l	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
e																		
ɪ	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
ŋ	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
ɪ											ɪ̃							
n			Ø			Ø	Ø	Ø		Ø	Ø	Ø		Ø		Ø	Ø	Ø
ɣ	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
ə/		Ø	Ø	Ø			Ø	Ø	Ø	Ø	Ø			Ø	Ø	Ø		Ø
Phrase duration (S)	1·2	1·1	1·0	1·1	1·2	1·1	0·9	1·0	1·1	1·1	0·9	1·0	1·2	0·9	1·0	1·1	1·1	0·9
Number of segments	10	9	9	9	10	10	9	9	9	9	8	10	10	9	9	9	10	9
Number of syllables	5	4	4	4	5	5	4	4	4	4	4	5	5	4	4	4	5	4

*** A blank space indicates that the segment was adult-like.**

ANALYSIS OF PHONOLOGICAL FORM **SUBJECT:** P9

Mean phrase duration (seconds): 1·77

Rank within group for mean phrase duration: 10

*REALISATION OF EACH SEGMENT IN EACH TOKEN

Token Number

Usual adult forms	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
/tʰ	d	d	d	d	d	d	d	d		d	d	d	d	d		d	d	d
ʉ																		ɜ
w																		
i																		
b																		
ɛə																		
z	∅	∅	∅	d	∅	d̆	∅	ž̥	∅	∅	z̆ð	∅	∅	∅	d	∅	z̆	∅
ʌʳ	ə̆									ə̆	∅		ə̆	∅	ə̆		∅	
pʰ	bʷ	p⁼	b		b	b	b	b	b		b	b		b	b	b	b	
l	∅	∅	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w	w
e				ĕ														
ɪ	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
ŋ	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n
ɪ																ɪ̃		
n																		
ð	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅		∅	∅
ə/																		
Phrase duration (S)	1·5	1·7	1·6	1·6	1·9	1·8	1·8	1·8	1·8	1·8	1·8	1·8	1·8	1·7	1·8	1·9	1·8	1·9
Number of segments	13	13	14	15	14	14	14	15	14	14	14	14	14	13	14	15	14	14
Number of syllables	7	7	7	7	7	7	7	7	7	6	7	7	7	6	7	7	6	7

*** A blank space indicates that the segment was adult-like.**

ANALYSIS OF PHONOLOGICAL FORM **SUBJECT:** P10

Mean phrase duration (seconds): 1.52

Rank within group for mean phrase duration: 5

*REALISATION OF EACH SEGMENT IN EACH TOKEN

Token Number

Usual adult forms	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
/tʰ	t˭	d	d	d	d			↑	t˭	d	d			d		d	d	d
ɑɪ								noise									ə	
w		v	∅									b						ç̰
i								↓										
b		v																
ɔe										ɔ	ɔ		ɔ					
z	z̥	z̥		z̥							z̥	z̥						z̥
ʌv	∅	∅		∅														
pʰ	b	p˭	β̞	p˭	b͡ɸ	b	p͡ɸ	p˭	b͡w	b͡w	b͡ɸ	b͡ɸ	b͡ɸ	b͡ɸ	b	b͡w	b	b͡w
l	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
e				†e/e					ɛ͡ə								e͡ə	
ɪ	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
ŋ	∅	∅	∅	∅	∅	∅	∅	∅	n	∅	∅	∅	∅	∅	∅	∅	∅	∅
ɪ	ʔɪ		ʔɪ			ʔɪ	ʔɪ				ʔɪ	ʔɪ	ʔɪ		ʔɪ		ʔɪ	ʔɪ
n									∅									
ɣ	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
ə/			∅						∅				∅		∅			
Phrase duration (S)	1.6	1.5	1.5	1.4	1.5	H⊛	1.5		1.4	1.4	1.4	1.8	H	1.5	1.4	1.3	H	2.0
Number of segments	12	12	11	12	13	13	13	noise	13	13	13	12	13	13	12	13	13	13
Number of syllables	6	6	6	6	7	7	7		6	7	7	7	6	7	6	7	7	7

† [e/e] indicates a discontinuity during the segment.

*** A blank space indicates that the segment was adult-like.**

⊛ H = Hesitation

ANALYSIS OF PHONOLOGICAL FORM SUBJECT: P11

Mean phrase duration (seconds): 1·34

Rank within group for mean phrase duration: 3

*REALISATION OF EACH SEGMENT IN EACH TOKEN

Token Number

Usual adult forms	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
/tʰ													d					
ʉ						ə	ə	əː										
w	†	∅	†	†	†	†	†	†			†	†	†	†	†	†	†	†
i																		
b					w	b̚	b̚				b̚		w	b̚^{w}			b̚	
ɔe													*ɔ/ɔɪ					
z	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
ʌ̃r	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅		∅	∅	∅	∅	∅	∅
pʰ			p̚^{ɸ}		p^{ɸ}	p̚				p̚^{ɸ}	p^{ɸ}	p̚						
l	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
e											eː							
ɪ	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
ŋ	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
ɪ	ʌ	ʌ	ʔɛ	ɛ		ʔɪ		ʔɪ̃	ʔɪ̃		∅		ʌ	ʌ	ʔɪ̃		ʔɪ	ʌ
n	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
ɣ	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
ə/	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
Phrase duration (S)	1·2	1·1	1·5	1·3	1·2	1·2	1·2	1·6	1·4	1·3	1·7	1·3	1·6	1·3	1·4	1·3	1·3	1·3
Number of segments	10	8	10	10	9	10	9	9	9	8	10	10	9	10	10	10	10	9
Number of syllables	6	5	6	6	6	6	6	6	5	5	5	5	5	6	6	6	6	5

† In these tokens the word 'little' is subsituted for 'wee' – realised as [ɣɪə]; [ɣɪʔə]; [ʋɪə]; [ɪʔɪ]; [ɣʌ]

*** A blank space indicates that the segment was adult-like.**

⊛ [ɔ/ɔɪ] – Indicates a perceived discontinuity within segment.

ANALYSIS OF PHONOLOGICAL FORM SUBJECT: P12

Mean phrase duration (seconds): 1·71

Rank within group for mean phrase duration: 8

*REALISATION OF EACH SEGMENT IN EACH TOKEN

Token Number

Usual adult forms	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
/tʰ										btʰ		btʰ		tɬ		ʔətʰ		tʰ
~~t~~																		
w					∅	w̆		∅					∅	∅			w̆	
i																		
b		w									bɸ		v					
æ																		
z	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
ʌ̃	ʔʌ		ʔə	ʔə		∅	ʔə	hə	ʔʌ	hə	ʔʌ	hʌ	ʔə	hə		hʌ		ʔə
pʰ	b	ɸ̄												b				
l	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
e	eː	ẽə	eː				eː	eː		eːə	eː	eː			eː		eː	
ɪ	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
ŋ	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
ɪ	∅	∅	ʌ		ʌ	ʌ	ʌ	ʌ	ʌ	∅	ʌ	∅	ʌ	ʌ	∅	ʌ	∅	
n	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
ð	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅	∅
ə/	ʔʌ	ʔʌ	ʔə	ʔə	ʔə	ʔʌ	ʔʌ	ʔʌ	ʔʌ	ʔə	ʔə	ʔʌ	ʔʌ	ʔʌ	ʔə	ʔʌ	hʌ	ʔʌ
Phrase duration (S)	2·5	1·7		1·8	1·6	1·7	1·6	1·6	1·6	1·8	1·8	1·6	1·5	1·4	1·9	1·5	1·6	1·7
Number of segments	10	10	11	11	10	10	11	10	11	10	11	10	10	10	10	11	10	11
Number of syllables	6	6	7	7	7	6	7	7	7	6	7	6	7	7	6	7	6	7

* A blank space indicates that the segment was adult-like.

SUMMARY OF 'P' SUBJECTS' REALISATIONS OF THE SEGMENTS INVOLVED IN THE TEMPORAL ACOUSTIC ANALYSIS.

Subj.	/t/ in 'two'	/b/ in 'boys'	vowel in 'boys'	/pl/ in 'playing'
P1	18* [tʰ]	18 [b]	8 [ɔe] 8 [ɔɪ̆] 2 [ɔ]	1 [pʰ] 5 [p⁼] 11 [b] 1 [b̚]
P2	15 [tʰ] 3 [d]	18 [b]	14 [ɔe] 3 [ɔɪ̆] 1 [ɔɪː]	11 [pʰl] 1 [p̚l]; 1 [bl] 1 [p͡f]; 3 [f] 1 [b]
P3	18 [ʔ]	18 [b]	15 [ɔe] 2 [ɔɪ̆] 1 [ɜ]	18 [b]
P4	2 [tʰ] 15 [d] 1 [ø]	18 [b]	17 [ɔe] 1 [ɔʔɔːɪ]	2 [p⁼] 16 [b]
P5	18 [tʰ]	18 [b]	18 [ɔe]	18 [pʰ]
P6	18 [tʰ]	17 [b] 1 [b̚]	18 [ɔe]	16 [pʰ] 1 [p̚] 1 [b]

* Number of occurrences of each realisation.

SUMMARY OF 'P' SUBJECTS' REALISATIONS OF THE SEGMENTS INVOLVED IN THE TEMPORAL ACOUSTIC ANALYSIS. (continued)

Subj.	/t/ in 'two'	/b/ in 'boys'	vowel in 'boys'	/pl/ in 'playing'
P7	16* [tʰ] 1 [tʰː] 1 [d]	10 [b] 1 [bʷ]; 1 [w] 1 [v], 4 [ʋ] 1 [ʋ̥]	10 [ɔe] 1 [ɔə] 1 [ɔɪ̆] 6 [ɔ]	1 [pʰl]; 6 [pʰ] 2 [pᶠ]; 1 [f] 1 [p̹ᶲ]; 1 [p̹] 1 [b̥ᶲ]; 4 [v]; 1 [v̥]
P8	15 [tʰ] 1 [t⁼] 2 [d]	16 [b] 1 [ᵝb̥] 1 [w]	18 [ɔe]	6 [pʰ] 1 [p⁼] 2 [pᶲ] 9 [b]
P9	2 [tʰ] 16 [d]	18 [b]	18 [ɔe]	4 [pʰw] 12 [bw] 1 [p⁼] 1 [bʷ]
P10	5 [tʰ] 2 [t⁼] 10 [d]	17 [b] 1 [v]	15 [ɔe] 3 [ɔ]	
P11	17 [tʰ] 1 [d]	11 [b] 4 [b̥] 1 [b̥ʷ] 2 [w]	17 [ɔe] 1 [ɔ/ɔɪ]	12 [pʰ] 2 [p̹] 4 [p̹ᶲ]
P12	13 [tʰ] 1 [t̪ʰ]; 1 [tᵈ] 1 [ˀətʰ] 2 [btʰ]	15 [b] 1 [bᶲ] 1 [w] 1 [v]	18 [ɔe]	15 [pʰ] 2 [b] 1 [ɸ]

* Number of occurrences of each realisation.

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